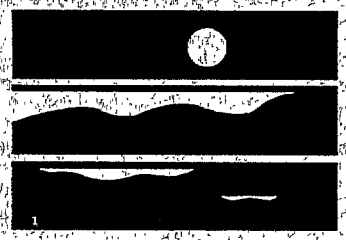


WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Indicators of Coastal Zone Quality: An Annotated Bibliography

April 1995
Publication 95-104
Printed on Recycled Paper

Indicators of Coastal Zone Environmental Quality: An Annotated Bibliography

April, 1995

Prepared by:
James M. Pacheco
School of Marine Affairs
University of Washington

Report 95-104

Shorelands and Water Resources Program
WASHINGTON DEPARTMENT OF ECOLOGY
Olympia, Washington 98504-7600

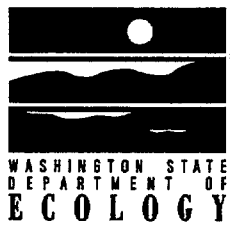
Coastal Zone Assessment Project

This report is one in a series of reports commissioned or completed by the Shorelands and Water Resources Program of the Washington Department of Ecology in fulfillment of its Coastal Zone Assessment Project. The project is dedicated to identifying measures of coastal zone environmental quality and success measures for Washington's Coastal Zone Management Program.

For additional information about the Coastal Zone Assessment Project, please contact the project manager:

Douglas J. Canning
Shorelands and Water Resources Program
Washington Department of Ecology
P. O. Box 47600
Olympia, WA 98504-7600
360.407.6781 (telephone)
dcanning@igc.apc.org (Internet)

This report was funded in part through a cooperative agreement with the National Oceanic and Atmospheric Administration with funds appropriated for the Coastal Zone Management Act of 1972. The views expressed herein are those of the authors and do not reflect the views of NOAA or any of its sub-agencies.



Recommended bibliographic citation:

Pacheco, James M. 1995. *Indicators of Coastal Zone Environmental Quality: An Annotated Bibliography*. Shorelands and Water Resources Program, Washington Department of Ecology, Olympia.

Preface

In recent years government has been challenged to assess its productivity, and individual government programs have likewise been challenged to assess their success. For some environmental and resource management agencies this has been relatively easy: water quality and air quality managers had for years been monitoring and reporting on environmental quality, and the environmental indicators are widely accepted. Other resource management agencies knew what to measure; they simply lacked the necessary funds maintain long-term monitoring programs. Yet other environmental and resource management agencies were truly challenged: there were no generally agreed upon success measures or environmental quality indicators. Coastal zone management, to a large degree, falls into that third category. Beginning in the late 1980s, the Washington Department of Ecology began addressing the business of measuring productivity and success through a series of projects and reports:

- the Washington Environment 2010 project which assessed current (1989) and future environmental conditions;

- the 1991 and 1993 State of the Environment reports which followed on from Environment 2010.

Early efforts by the Shorelands and Coastal Zone Management Program focused on measures such as the number of permits reviewed, or the amount of technical assistance provided to local governments. But these are not productivity or success measures, nor do they characterize the coastal zone; they are merely activity measures, or in the vernacular, 'bean counts.' Part of the problem lies in the general nature of shorelands and coastal zone management under Washington's Shoreline Management Act and the federal Coastal Zone Management Act. The mandates and goals of these laws can be summarized as follows:

- foster appropriate development and land use;

- protect marine and aquatic water quality, habitats, and resources from the direct and cumulative adverse effects of development and other human activities;

- prevent inappropriate development and land use in high-hazard areas;

- provide for public access and recreational opportunities; and

- provide special area management for important shoreland and coastal areas.

Some of these goals do not readily translate into on-the-ground or in-the-water measures of success.

This report is part of a project initiated in 1994 by the Shorelands and Coastal Zone Management Program to identify meaningful and practical measures of the state of the coastal zone. Legislators and the public are right to expect their governmental programs to yield productive results. Resource management agencies should report on those results in a way that makes sense, is scientifically valid, and is cost effective.

In this task we have reviewed and assessed the scientific and professional literature. The project was ably carried out by James Pacheco, a graduate student at the School of Marine Affairs at the University of Washington. Some of the problems we encountered in designing and completing this literature review speak to the broader problems of resource assessment already mentioned:

> The business of assessing environmental quality, governmental productivity, and government program success is young, especially in coastal zone management. Not surprisingly, we had difficulty identifying key words by which to conduct our search of the scientific and professional literature.
>
> Coastal zone management as a discipline and a governmental activity seems to be poorly recognized in some quarters. A good body of the coastal zone management literature was indexed only in the engineering literature indexing services simply because the publisher of the biennial Coastal Zone Symposium happens to the American Society of Civil Engineers. Only when our initial search failed to turn up known titles did we learn of this quirk.

This report reflects only our review of the scientific and professional literature. Other tasks in the project will review governmental agency reports and workshop proceedings, evaluate established monitoring programs, and identify the relevant data sets available for Washington's coastal zone.

Douglas J. Canning
Project Manager
Coastal Zone Assessment Project

Table of Contents

1. Introduction

The coastal zone represents the epitome of a limited resource with many competing interests vying for its use. Over twenty years ago Congress took notice of the environmental degradation taking place in the coastal zone, the competing interests, and the inability to properly manage the coastal resource. To ameliorate these problems, Congress passed the Coastal Zone Management Act of 1972 which challenged coastal states to develop and implement programs to manage and protect their coastal resources. Washington is one of the many states that took up the challenge. The Washington state Shoreline Management Act of 1971 is the basis of Washington's federally approved coastal zone management program.

Has all this worked? Has coastal zone management improved the quality of our coastal resources? Does the public see a benefit from the increased stewardship? While there are anecdotal data that answers these question affirmatively, these are unreliable measures and should not be the sole basis in which to evaluate the nation's coastal zone management program. How then should coastal zone managers measure their success? In the early years after the passage of the Coastal Zone Management Act, researchers and practitioners began to stress the need to formulate meaningful and measurable evaluative criteria, among which are quantitative measurements (abstracts of these papers are listed in section "Coastal Zone Management Review". Have researchers and practitioners risen to the challenge? Have they developed indicators of environmental quality for the coastal zone?

In this first phase of the project, we searched the scientific and coastal zone management literature in an attempt to develop a list of useful environmental quality indicators for the coastal zone. The goal was to develop a list of indicators that are both measurable, i.e., they should be quantitative, and economical, i.e., they should be attainable within normal budgetary constraints. They should also be usable by natural resource managers as well as having intuitive and significant meaning to the general public.

This literature review sought to locate potential evaluative criteria as discussed in peer reviewed journals and "gray literature" such as non-reviewed journals, symposium and conference proceedings. The search was conducted at the University of Washington using the on line catalogue and the following CD-ROM data bases: Cambridge Scientific Abstracts, National Technical Information Service, Life Sciences Abstracts, Water Resources Abstracts, Fish and Fisheries, and Compendex. This search strategy was designed to be comprehensive in that it is very multi-disciplinary, but it was not exhaustive.

During the literature search, I used two different strategies. In one strategy, I used the key word search terms such as ((ENVIRONMENTAL OR STRESS OR WATER QUALITY) with INDICATOR"). I then restricted the search to those papers dealing with "COASTAL OR MARINE OR ESTUARINE OR (PUGET SOUND)" issues. This strategy turned up sources mainly from the peer reviewed scientific literature. The second strategy used terms such as (COASTAL ZONE MANAGEMENT WITH (EVALUATION OR REVIEW)). This naturally turned up sources form the coastal zone management literature.

The initial search turned up over 500 sources. The abstracts of these sources were read and evaluated for their applicability to this project. The initial findings were culled using the following criteria.

1) The indicator should deal with an outcome. Programmatic papers were not considered useful to this project. Since process problems are procedural in nature, they do not avail themselves to quantitative evaluative criteria thus are inappropriate to use as indicators. However, formative evaluations can give feedback to managers and legislators to determine if process problems are being properly dealt with. Outcome problems of the other hand are much easier to portray as an indicator. An assumption made by this review is that as an indicator shows a problem being improved, especially if good, acceptable, and harmful levels have been determined, that is an indicator of quality

2) The source should deal more with the ability of the indicator in question to determine the quality of the coastal resource rather that the effects of the coastal resource on that indicator. This was most apparent in choosing papers dealing with bioindicators.

3) The indicator should be easily reproducible, recognizable and have an intuitive "feel" as an indicator of coastal zone quality. For example, some cellular or biochemical tests may have a good scientific basis to support its use an indicator, but they are to technical to be easily understandable and potentially too expensive to be useful as an indicator.

These remained our criteria for "useful indicators," but, when it became apparent that most of the sources did not meet this criteria, sources not necessarily useful to the indicator project were kept. These are used to compare and contrast the different type of research and to show the different directions researchers are taking.

This shorter list was compiled and separated into five subject areas. In each subject area, relevant papers are discussed, cited, and presented in abstract form. All presented papers share a similar format as follows:

Author(s). Date. Title. Journal or Book or Proceedings. Publisher.

ABSTRACT: The authors abstract taken from the paper or the indexing service.

ANNOTATION: Any relevant information not in the abstract is included here. In cases where an abstract is not provided the annotation will summarize any relevant information.

The first is a small group dealing with perception. It looks at how researchers and practitioners and the public perceive problems in the coastal zone. It also looks at what indicators appear to be important to these groups and compares them with what is being promoted in the literature.

The second, third, and fourth groups deal with the more scientific oriented areas of water and sediment quality and bioindicators. Two groups of bioindicators have a particularly large research base and are treated separately. These are papers dealing with sediments and benthic

and demersal organisms and those dealing with bivalves with a sub-section describing and illustrating the success of the national mussel watch program.

The fifth group focuses on the more socially inclined research of coastal zone management. It includes three of the eight "improvement objectives" identified by Congress in its 1990 reauthorization of the Coastal Zone Management Act and reviewed in the 1992 Washington State Coastal Zone Section 309 Assessment and Strategy paper. The three areas included are "coastal hazards," "public access," and "marine debris." Some articles on wetlands were discovered, but these only dealt with describing restoration attempts or arguments favoring wetland preservation. These topics were not useful to the project, therefore, the subject was eliminated. The four other objectives were considered too programmatic to be useful to this study. Other subjects uncovered during the literature review include a section on previous CZM evaluations and one dealing with buffer zones. A final section dealing with public participation is admittedly programmatic in nature, but it does offer supporting evidence as to why we are still dealing with the problem of a lack of good quantifiable indicators for the coastal zone.

2. Perceptions of Indicators

One problem with developing a set of indicators of coastal zone quality is the differing perceptions of problems held by policy makers, natural resource managers, interest groups, and the general public. This chapter reviews articles that highlight some of those differences, the problems those differences can cause, and recommendations for improvement.

2.1 Problems with Differing Perceptions

Scientists, resource managers, and the public have different knowledge they bring to their impressions and values of the shore. Not surprisingly, this results in different perceptions of what is meaningful or important. For example, if the parameters used by coastal zone managers are not easily understood by the public (O'Connor et al. 1986, Wolfe and O'Connor 1986), or do not take into consideration the manner in which the resource is used (West 1987 and West 1989), the public may neither understand nor see the value in the program. This makes the policy or program vulnerable to critiques of being ineffective, inefficient or too expensive, which could lead to its elimination.

O'Connor, J.S.; Pugh, W. L.; Wolfe, D. A.; Dewling,-R. T. 1986. Protection of natural resources through environmental indices. *Sea-Technol.* 27(9): 31-33

ABSTRACT: While many available indicators are useful in pollution assessment, simple indices are often most advantageous from the decision-maker's perspective. Governments have long used indices of their economic conditions. For many of the same reasons, including the need to understand influences of environmental quality on economics, indices of marine environmental quality are expected to be developed and used in the near future. Indices, unlike the direct measurements on which they are based, include some technical interpretation, and this important benefit is transmitted to the layman and the general public. Indices, therefore, can be tangible and readily interpreted without reference to additional standards or reference values. Direct measures alone of most environmental features are marginally interpretable in the managerial context. Improved indices of pollutant degradation are needed as guides to design monitoring programs. It is evident that major collaborative efforts would be necessary to monitor effectively on a national basis, just to coordinate monitoring for compliance with existing laws and regulations which monitor for trends in contamination and fate and effects.

Douglas A. Wolfe and Joel S. O'Connor. 1986. Some limitations of indicators and their place in monitoring schemes. pp 878-884 in: *Oceans '86 Conference Record: Science Engineering Adventure. Vol. 3 Monitoring-Strategies Symposium*. Marine Technology Soc., Washington, DC, New York, NY.

ABSTRACT: Indicators of marine environmental quality in problem oriented monitoring must be matched to management needs. Indicators, carefully chosen, applied, and inter-

preted, can help us understand environmental status, and perhaps help to fore cast environmental changes. Understanding the causal mechanisms and inter-relationships under lying changes in indicator values usually relies on models derived from previous research. The management focus and utility of marine environmental monitoring programs would be greatly improved by 1) clear definition of management objectives and information needs; 2) more direct representation of management values in the indicators selected for monitoring; 3) specification of appropriate management actions at different thresholds in the monitored indicators; and 4) design of statistically sound sampling with explicit recognition of credible impact hypotheses, desired detection limits, and ambient variability. For many indicators, indexes may be an effective means of describing and communicating environmental trends.

West, Niels. 1987. Estuarine quality use and public perception. pp 804-811 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal and Ocean Management. v 1.* American Society of Civil Engineers, New York.

ABSTRACT: Coastal environmental quality is determined on the basis of a relatively small number of biochemical and physical parameters which may bear little relation to the intended use of the water. This paper reports on the perceptions of five Narragansett Bay user groups (boaters, beach-goers, residents, tourists and shellfishermen pertaining to both the dry shore and nearshore of Narragansett Bay. While the users were in general agreement about the ends of the 'environmental continuum,' considerable variation exists in the weights accorded and the specific environmental parameters cited by the five user groups. None of the environmental factors mentioned included those which traditionally have been used to measure the quality of the dry shore and nearshore. The paper concludes with a call for the inclusion of parameters important to the users in the determination of water classes and standards above and beyond the conventional biochemical and physical parameters collected at present. (Author abstract) 6 refs.

ANNOTATION: Because financial resources are limiting, it makes little sense to judge water quality with a parameter which is inconsistent with the actual use of the water resource. Therefore, parameters important to the various user groups should be included when determining water quality standards.

West, N. 1989. A preliminary review of water quality parameters and recreational user perceptions of nearshore water quality. *Journal of Coastal Research* 5(3): 563-572.

ABSTRACT: Substantial discrepancies exist between the quality of the nearshore defined scientifically and the quality of the water as viewed (perceived) by the many users of that environment. Discrepancies between scientifically defined water quality and the manner in which the quality of the water is perceived by the users present both opportunities and obligations for the coastal and nearshore manager and policy maker. Shore and nearshore areas, which from a scientific point of view are classified as marginal, may be useful for some recreational activities. It is suggested that additional non-scientific water quality parameters be included in future water quality surveillance efforts which are meaningful to both existing and new users of that environment.

2.2 Public Perception

What are the public's concerns? What do they consider to be important indicators of environmental quality in the coastal zone? Only one author described parameters important to the public. Eichbaum (1990) describes four areas of public concern and suggests that they be integrated into the management system: whether the area is swimmable or fishable, a concern that living resources protected, and that public health is safeguarded. Unfortunately, these four areas of concern do not directly convert to quantifiable indicators. However, existing indicators and monitoring data can be described is ways that address the public's concerns. For example, instead of simply reporting dissolved oxygen as just another impersonal water quality parameter, it could and be compared with the minimum level needed to support salmonids. Researchers need to make the effort phrase their data in more meaningful ways.

Public perception can also be important to guide programmatic decisions. These are not useful as an environmental indicator, but like the previous examples, they can guide future research and programs. Fenton and Syme (1989) surveyed the publics perception on what constitutes appropriate development in the coastal zone. They found that low rise developments and marinas were preferred over industrial, commercial, and high rise developments. Fletcher et al. (1989) dealt with perceptions of beach safety, but within this seemingly irrelevant study, they recorded that the public values the beach for its scenic value and its recreation value. Indicators based on those two values would therefore be meaningful to the public. Other authors support the value of scenery, but in an indirect way. Often an author uses language too indefinite to be useful in developing an indicator (e.g. Kuroyanagi et al. 1983), or the author just casually mentions that a certain factor is important and then moves on with the subject of the article (Williams 1992).

One group of authors focused on the problem of coastal erosion. Terich and Gabriel (1987) found that erosion has little effect on property values. The availability of insurance may be a contributing factor to this finding. Kucma-Kenny and Nordstrom (1985) found a similar indifference, but thought it was due to a lack of communication between the public and coastal zone managers. Ives and Furuseth (1988) on the other hand found that the public was aware of the problem, and that the erosion risk can be increased by human intervention. Clearly, individual case studies are not generalizable.

Research involving the public's perception did not turn up any useful indicators, but it has offered some insight on how to better present data, and has shown that coastal zone managers have not been successful in communicating their perception of coastal zone problems.

Eichbaum, W.M.; Bernstein, B.B. 1990. Current issues in environmental management: A case study of southern California's marine monitoring system. *Coastal Management* 18(4): 433-445.

ABSTRACT: A case study panel of the National Research Council's Committee on Systems Assessment of Marine Environmental Monitoring analyzed the monitoring system in the Southern California Bight. The goal of this assessment was to identify

monitoring's contribution to decision making and recommend how effective monitoring programs could be designed. The committee viewed monitoring as part of a management system including public concerns, laws and regulations, and the decision-making infrastructure. In assessing this larger system, the panel found many monitoring programs in the bight, regulated and performed by a variety of public and private agencies. These programs had contributed to the understanding of impacts around point sources.

ANNOTATION: The public's concerns were stated as four questions: (1) **Is it safe to swim in the ocean?** (2) **Is it safe to eat local seafood?** (3) **Are fisheries and other living resources being protected?** (4) **Is the health of the ecosystem being safeguarded?** There is also a concern that monitoring is not addressing these questions. Part of this problem is that much of the monitoring data is to technical to be useful to the public. An effort needs to be made to translate monitoring data into information that is useful to both coastal zone managers and to the public.

2.2.1 Appropriate Development

Fenton, D.M. & Syme, G.J. 1989. Perception and evaluation of the coastal zone: Implications for coastal zone planning. *Coast. Manage.* 17(4): 295-308.

ABSTRACT: 509 Respondents completed a survey that assessed their knowledge of the metropolitan coast; the acceptability of industrial, commercial, high-rise, and marina developments; and community perceptions of the important planning criteria for coastal development. Analysis, by means of a modified repertory grid methodology, of respondents' coastal knowledge indicated that the coast could be classified into four perceptual units that, when used with existing landform and land use classification, could be used to assess development location and the social impact of proposed developments. By analysis of responses to coastal maps, sketches, and verbal descriptions, it was found that **only marina and low-rise developments were seen as acceptable forms of coastal development.**

2.2.2 Scenery

Fletcher,-J.E.; Kaiser,-R.A.; Steele,-R.J.Perceptions of beach safety: A comparison of beach users and managers. 1989. *Coastal Management* 17(4): 349-359

ABSTRACT: Today's beach manager must balance legal obligations to protect users from injuries with recreation users' expectations for reasonably safe and enjoyable recreation opportunities. Thus beach managers must have a thorough understanding of their legal obligations as well as the expectations of their recreation users if they are to formulate risk-management programs that satisfy both. This study outlines the legal obligations of beach managers in protecting users and presents survey findings that demonstrate that managers' expectations for safety-related services may be different from the expectations of recreation users at a particular beach park. Although the study was conducted at four Texas beach parks, the legal principles and methodology presented can be used by beach managers in their formulation or update of risk-management programs for beaches in other states.

ANNOTATION: In addition to the public surveys of why they went to the beach, two potential indicators developed. These are the importance of **scenery** and the **recreation value.**

Kuroyanagi, Akio and Takeo Kondo with Academic Advisor Prof. Wataru Kato. 1983. Evaluation of the Visual Effects of the Coastal zone. p 2222 in: *Coastal Zone '83: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: The ocean is different from land in that its scenery consists of a vast and simple blue sea and blue sky, and coastal areas are an extremely delicate space both ecologically and geographically. Therefore, the basis for the development of a visual environment in the coastal zones requires harmonious space consisting of extended space and a clear view. The space in such an environment should possess coordinated unity instead of a partial balance. However, under the current circumstances, optimum utilization of the coastal areas has been made possible by reclamation and development, and factories, industrial complexes, and other large enterprises blanket the areas. Such development, being different from the conventional means of land usage, in turn, is disturbing the harmony of the environment, often resulting in conflicts with local residents. Moreover, various structures erected in the coastal areas occupied by specific users hinder the local residents of not only **physical access** but also **visual access**, thus causing their spiritual alienation from the coast. For this reason, emphasis on the ecological, cultural, historical, and aesthetic considerations must be given in this field of the coastal zones for maintenance of amenity, as well as on the significance of economic development. It is only after sufficient scientific clarification of the interrelationships between man and the coastal environment that standards and methods for future evaluation of the pertinent value of the coastal environment can be drawn.

Williams, A.T. 1992. The quiet conservators: Heritage Coasts of England and Wales. Ocean Coast. Manage 17(2): 151-167.

ANNOTATION: Williams describes the purpose and progress of UK Heritage Coasts which seeks to preserve the most scenic coastlines of England and Wales through non-statutory persuasive means. Briefly mentioned in the article is the public's desire to conserve the **quality of scenery** and to foster **leisure activity (recreation)**, and the acknowledgment that these values are highly subjective.

2.2.3 Erosion

Terich, Thomas A.; Gabriel, Anthony D. 1987. Effect of erosion upon coastal property values. pp 2391-2401 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal and Ocean Management. v 2.* American Society of Civil Engineers, New York.

ABSTRACT: The effect of long-term severe erosion upon **coastal property values** is tested at a site along the Pacific Coast of Washington State. Statistical analysis of mean sales values suggests the erosion has had little impact on land values. This conclusion

must remain tenuous because of the nature of the site. The problems and issues of studying the economic impacts of coastal erosion are presented. (Author abstract)

ANNOTATION: The public did not appear to be concerned with the potential of erosion damage when purchasing a piece of property. The potential of insurance may be a factor in erosion's lack of effect on property values. The author found the assessor's lowering of property value for the purpose of tax assessment had a greater effect than erosion.

Gail A. Kucma-Kenny and Karl F. Nordstrom. 1985. Communication of coastal erosion information to shorefront residents: the user perspective. p 327 in: *Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ANNOTATION According to managers and policy makers, coastal erosion problems are reaching critical proportions along much of the US Shorefront. These researchers found that the public is not very interested or concerned about **coastal erosion** unless they are being impacted.

Ives, S.M.; Furuseth, O.J. 1988. Community response to coastal erosion: The view from two North Carolina beach areas. *Ocean and Shoreline Management* 11(3): 177-193.

ANNOTATION: Research on response to coastal erosion suggest that residents of both communities are aware of the hazard, and view it as a natural process with which they must cope. They recognize that **erosion risk** is increased by human action, and hence are strongly in support of non-structural approaches at the local level. Residents also indicate strong support for post-disaster assistance from federal and state governments, moderate support for structural techniques, but relatively weak support for subsidized hazard insurance.

2.3 Perceptions of Coastal Zone Managers and Researchers

The perceptions of managers and researchers of course differ from those of the general public. For example, the National Status and Trends Program focuses on water quality data and monitors nationwide levels of toxic chemicals in fish, shellfish, and sediments. Turgeon et al. (1993) gave a good comprehensive explanation of the program. Burroughs and Lee (1988) also show that water quality measurements are being used as an indicator for program evaluations. Although water quality measurements are easily quantifiable, which makes them useful to researchers and coastal zone managers, they are not always presented in a context understandable by the lay public.

Some research has included parameters which would be understandable by the public, however, these types of papers were not very common. Of the indicators described in Piccolo (1991), tumors in fish livers, closed shellfish beds, and loss of habitat would be most useful because they most closely relate to the public's concerns. Sempere and Rowan (1983)

gives an early example of a study that included a local perspective concerning coastal zone problems. It was not a very comprehensive inclusion as it focused on local leaders, but it was a start.

Although the importance of the public's perception of a chosen indicator has been in the literature for at least seven years, many indicators proposed by researchers do not included public perception as a factor. When newer methods to determine environmental quality were proposed, instead of simplifying the research model, most researchers tended to develop and recommend a more complex set of indicators, with complexity increasing over time. Long (1983) simply prescribed a multidisciplinary approach. This was followed by Cendreo (1989) who wrote that research should be "pluridisciplinary," that the cooperation of the natural and social sciences and engineering is essential for proper understanding of the complex problems involved in coastal zone management. Underwood and Peterson (1988) developed an ecological framework. Nelson (1990) expanded on this ecological model and developed a very specific and quantitative index of biotic integrity for coastal systems. These models (at the time) may have been more environmentally and ecologically sound and gave managers a better overall indicator of quality, but they are probably too technical to be useful to the public.

2.3.1 Useful Parameters and Research

Turgeon, D.D.; Gottholm, B.W.; Wolfe, D.A.; Roberston, A. 1993. NS&T national benthic surveillance project: contaminants in fish tissues. pp 3474-3483 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management v 3.* American Society of Civil Engineers, New York.

> ABSTRACT: The National Benthic Surveillance Project, part of NOAA's National Status and Trends (NS&T) Program, has been regularly measuring more than 70 contaminants in **liver tissue of selected benthic fish** species and in estuarine and coastal sediments since 1984. Contaminants monitored by the NS&T Program include 16 major and trace elements, 9 chlorinated pesticides and 6 isomers of DDT, DDD and DDE; 20 polychlorinated biphenyl congeners; 24 polynuclear aromatic hydrocarbons (PAH); butyltins; and, at some sites, toxaphene. Concentrations of fluorescing PAH metabolites are measured in fish bile, and histopathology and other biochemical biomarkers of contaminant exposure are also determined in the liver tissue. Primary species of fish represented in the national NS&T monitoring database include: flathead sole (*Hippoglossoides elassodon*), white croaker (*Genyonemus lineatus*), starry flounder (*Platichthys stellatus*), Atlantic croaker, (*Micropogonias undulatus*), spot (*Leiostomas xanthurus*), and winter flounder (*Pleuronectes americanus*). This paper examines correlations in concentrations of selected trace elements (Pb, Zn, Ag, Hg, Cd, and Cu) and organic chemical classes (DDT, PCBs, and total chlordane) in these six fish species and in associated surficial sediments. (Author abstract) Refs.

Burroughs, R.H.; Lee, V. 1988. Narragansett Bay pollution control: An evaluation of program outcome. *Coast. Manage.* 16(4): 363-377.

ABSTRACT: Program evaluation is applied to estuarine management. Point source loadings of **oxygen demanding organic material** and ambient conditions of **bottom water dissolved oxygen** in the upper reaches of the Narragansett estuary were examined over recent decades to determine the effects of a sewage treatment plant in reducing pollution. Two tests of program outcome are presented. The first demonstrates that a statistically significant increase in bottom water dissolved oxygen is correlated with a sewage treatment plant upgrade. The second analysis shows that these improvements in water quality exceed those that could be attributed to improved background conditions caused by reduced loading from the major river.

Piccolo, Vallana M. 1991. Pollution control strategies of the Puget Sound water quality management plan. Puget Sound Water Quality Authority. pp 904-915 in: *Coastal Zone '91: Proceedings of the seventh Symposium on Coastal and Ocean Management v 2.* American Society of Civil Engineers, New York, NY, USA.

ABSTRACT: In 1988 EPA designated Puget Sound as an estuary of national significance under section 320 of the Clean Water Act. Due to its natural beauty, favorable climate, and economic health, the Puget Sound Basin continues to grow in population. Indicators of pollution, however, began to emerge in the Sound, particularly in urban embayments. These indicators included **contaminated sediments, tumors in fish livers, closed shellfish beds; loss of habitat, and high levels of some toxics in certain marine mammals.** In response to growing public concern, in 1985 the Washington State Legislature created the Puget Sound Water Quality Authority to develop a comprehensive management plan to reduce and eventually eliminate harm to Puget Sound from pollution. The Authority was also charged to oversee implementation of the plan. The comprehensive management plan has been completed and it includes a wide range of pollution control strategies which address point source discharges, stormwater runoff and other nonpoint sources, contaminated sediments, wetlands and habitat protection, shellfish bed restoration, spill prevention and response, monitoring and research, public involvement and education, as well as funding mechanisms and other supporting programs. This paper briefly outlines the pollution control strategies in each program and identifies some of the successes and challenges resulting from implementation. (Author abstract)

James M. Sempere and Dana C. Rowan. 1983. Connecticut embayments study: a basis for allocating state and local resources for coastal management in the 1980s. p 2251 in: *Coastal Zone '83: Proceedings of the third symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York, NY, USA.

ABSTRACT: The Connecticut Embayments Study documents a unique and systematic analysis of environmental problems facing the Connecticut coastline. Developed under a mandate of the Connecticut General Assembly (Special Act 80-45), the Study includes analysis of seven (7) key environmental problem categories: **shoreline erosion, siltation, water pollution, flow constrictions, eutrophication, wetland loss, and shellfish loss.** This

paper describes the methodology developed and selected results obtained by the study, and focuses on the realized and future management uses of the study.

2.3.2 Questionable Parameters and Research

Edward R. Long. 1983. A multidisciplinary approach to assessing pollution in coastal waters. p 163 in: *Coastal Zone '83: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: An approach to assessing toxic substance levels and effects in coastal waters has been devised and applied in Puget Sound by NOAA. This **step-wise approach** was implemented in an effort to determine the nature and extent of toxic chemical problems and to identify high-priority areas for focusing clean-up activities. It could be used elsewhere in a variety of applications. This paper briefly describes the approach, the rationale for each step and selected results obtained from Puget Sound.

Cendreo, A. 1989. Land-use problems, planning and management in the coastal zone: An introduction. *Ocean Shoreline Manage.* 12(5-6): 367-381.

ABSTRACT: A brief review of the main environmental problems affecting the coastal fringe is presented. The types of resources present in it are considered, as well as the existing trends in the occupation of coastal areas, particularly in relation to tourism and recreation. The problems of environmental degradation, competing land-uses, planning and management produced as a result of human occupation and resource exploitation are discussed. Finally, some comments are made on the tasks that should be undertaken to reduce existing problems, both in the field of research and in the realm of planning, legislative and administrative actions. The need for an **integrated policy of research, planning and management** at the European level is stressed.
AN: Cendreo lists a number of existing problems, but cites **coastal erosion** as perhaps the most widespread coastal hazard throughout the world, affecting 50% of the world's coasts and contributing as much sediment as all rivers. To address these problems, the author recommends a **"pluridisciplinary" approach**, that the cooperation of the natural and social sciences and engineering is essential for proper understanding of the complex problems involved in coastal zone management. However, there is no reference to the public's ability to understanding the research.

Underwood, A.J.; Peterson, C.H. 1988. Towards an ecological framework for investigating pollution. *Mar. Ecol. Prog. Ser.* 46(1-3): 227-234.

ABSTRACT: Three aspects of the study of effects of pollution in marine systems are discussed. First is the evaluation of relative sensitivities and reliabilities of different methods of detecting pollution, including a brief contrast of processes operating in mesocosms and in the field. Second is the problem of interpretation of pollution, i.e. determining the importance of the observed effects of pollution to the biological system. Finally, there is the problem of prediction of future consequences of pollution. A **mixture of different**

types of measures allows the best synthesis of predictive power while providing the most useful information for interpretation of the consequences of pollution to a marine system.

Nelson, W.G. 1990. Prospects for development of an index of biotic integrity for evaluating habitat degradation in coastal systems. *Chem. Ecol.* 4(4): 197-210.

ABSTRACT: A multivariate index for assessment of habitat quality and its degradation, the **Index of Biotic Integrity (IBI)**, has been developed for stream fish communities. The extension of the IBI concept to coastal waters is proposed by the development of an estuarine IBI based on **macrobenthos** and **submerged aquatic vegetation.** Eleven variables are proposed for inclusion in the index, although further consideration of the appropriateness of several variables is required. It is concluded that development of an IBI for coastal systems is feasible.
AN: The eleven variables are (1) species richness and composition of macrofauna; (2) percent of individuals as amphipods; (3) percent of individuals as opportunistic species; (4) percent of individuals as polychaetes/oligochaetes; (5) percent of individuals as molluscs; (6) percent of individuals as deposit feeders; (7)percent of individuals as carnivores; (8) Mean number of individuals per sample; (9) dominance of most abundant species; (10) mean size of organisms in the habitat; and (11) percent cover of submerged aquatic vegetation.

2.4 Citizen Monitoring Parameters

Various management agencies and environmental interest groups have explored the concept of citizen monitoring. This topic is also discussed in the public participation section, but it also shows the kinds of parameters these agencies and environmental groups deem suitable for volunteer monitoring programs.[1] This approach is useful because it allows for the inexpensive collection of data and it helps to educate the public on the more sophisticated but unfamiliar indicators of quality in the coastal zone. Programs as those described in Lee (1985) and Campbell and Ellett (1991) may help bridge the gap between the differing perceptions of problems and solutions in the coastal zone and provide for useful indicators of quality in the coastal zone.

Lee, V. 1991. Salt Pond Watchers, citizen monitoring for better government decisions. p 1241 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management v 2.* American Society of Civil Engineers, New York.

ABSTRACT: Since 1985, 50 Salt Pond Watchers have monitored the effects of development on 7 estuarine bays in Rhode Island. Volunteers test the waters biweekly for

[1] There has been a lively debate for years over the value of citizen or volunteer monitoring programs as a supplement to governmental monitoring programs. The issue is largely one of data integrity and quality control concerns versus the public education and involvement value of volunteer monitoring programs.

temperature, dissolved oxygen (LaMotte kit), **salinity** (salinometer), and **turbidity** (Secchi disk), and collect water samples for **chlorophyll, nutrient, and fecal coliform testing** at university, state, and federal labs. Volunteers also check for **eelgrass-wasting disease**, conduct **waterfowl counts**, and **measure rainfall**. Results are used by state and municipal government agencies for shell fish closures, zoning changes, wastewater management policies, and state water quality reports for EPA. The program's goals are to develop long-term trends for use in management decisions and research and to foster a sense of stewardship for these resources. Volunteers assist with coordination, data management, and editing a quarterly newsletter, 'Salt Ponds.' Funding is from Rhode Island Sea Grant with in-kind contributions from URI, the Rhode Island Department of Health, and the Federal Food and Drug Administration. (Author abstract)

Campbell, Gayla; Ellett, Kathleen. 1991. Citizen monitoring component of the Maryland Targeted Watershed Project. pp 1231-1240 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management v 2.* American Society of Civil Engineers, New York.

ABSTRACT: The Alliance for the Chesapeake Bay has conducted a water quality testing program using volunteers since July of 1985. This program has laid the foundation for volunteers to help Bay managers augment data gathering in near-shore areas of tributaries to the Bay. In the Spring of 1989, the State of Maryland began the Targeted Watershed Project which is a cooperative effort by local, state, federal government agencies and private organizations. Management of these small tributaries could help improve aquatic values not only within each watershed but also in the larger downstream tributaries including the Chesapeake Bay. The Alliance is recruiting and training citizens to monitor seven different physical and chemical variables on a weekly basis. Quality assured, citizen generated data in the targeted watershed project will enhance the capability of implementing effective management practices. Other citizen participation activities are essential to the project. These include streamwalk surveys, cleanups, scout projects, wildlife habitat enhancement and watershed reforestation. It is hoped that the success of these projects will lead to additional watershed programs in the Chesapeake Bay and that citizen involvement will continue to be an integral part of every program. (Author abstract).
AN: The seven physical and chemical variables were **dissolved oxygen, pH, turbidity, air and water temperature, daily precipitation**, reading USGS staff gauges, and site and weather observations

3. Direct Measurements and Bioindicators

Most of the useful indicators of environmental quality focus around water quality standards and biological indicators. Water quality indicators are an extension of the early 1900s drinking water standards. These are the oldest of all indicators, and debates over efficacy, advantages, or limitations are rare. Despite their limitations for environmental characterization, direct measurements of water quality are still useful. Measurements of dissolved oxygen, pH, turbidity, or heavy metals are necessary parameters for assessing public health and water quality standards. They also have great value for comparison with historical readings to show how water quality has either been improved or degraded. Although chemical analysis can indicate the presence of contamination, it does not necessarily determine its effect on the environment. This limitation lead researchers to look at the environmental effects on living organisms which lead to the use of bioindicators for determining environmental quality.

3.1 Direct Measurements

Since there is a long history of direct measurement of physical or chemical parameters, researchers have had the time to develop standard methods which make this field a good candidate for an environmental quality indicator. Burroughs and Lee (1988) give a representative example of how existing water quality standards can be used to evaluate the effectiveness of various environmental programs. Other examples of how direct measurements are still being used will be discussed in the Benthos and Bivalves sections.

The problem with direct measurements of water quality is that they only provide a snapshot view of the environment. Because of the often dynamic nature of coastal systems, this is not always the best measurement of environmental quality (Segar and Stamman 1986). Comprehensive time series testing can ameliorate this drawback, but the frequent sampling and testing requirements tend to be cost prohibitive.

Burroughs, R.H.; Lee, V. 1988. Narragansett Bay pollution control: An evaluation of program outcome. *Coast. Manage.* 16(4): 363-377.

> ABSTRACT: Program evaluation is applied to estuarine management. Point source loadings of oxygen demanding organic material and ambient conditions of bottom water **dissolved oxygen** in the upper reaches of the Narragansett estuary were examined over recent decades to determine the effects of a sewage treatment plant in reducing pollution. Two tests of program outcome are presented. The first demonstrates that a statistically significant increase in bottom water dissolved oxygen is correlated with a sewage treatment plant upgrade. The second analysis shows that these improvements in water quality exceed those that could be attributed to improved background conditions caused by reduced loading from the major river.

Segar, D.A.; Stamman, E. 1986. Monitoring in support of estuarine pollution management needs. pp. 874-877 in: *Oceans '86 Conference record: Science Engineering Adventure. vol. 3. Monitoring Strategies Symposium*. Marine Technology Soc., Washington, DC; IEEE, New York.

ABSTRACT: Estuaries are extremely dynamic ecosystems in which substantial spatial and temporal heterogeneity exists, and dramatic climatically-controlled biological changes can occur from year-to-year. As a result, the traditional monitoring of biological populations or of environmental pollutant concentrations is usually ineffective since, even if very large numbers of samples are taken, environmentally-significant degrees of pollutant-induced change cannot be statistically isolated from natural change. A successful, estuarine pollution monitoring program must include a hierarchy of direct and indirect measurements, and the program results must be carefully evaluated to derive a cohesive picture of the state of the estuarine system.

3.2 Bioindicators

Chemical analysis can indicate the presence of contamination, but not its effect on the environment. Since these effects are commonly biological, it is quite logical that researchers would look toward bioindicators for determining environmental quality (James 1979). Unfortunately, the time period searched in this literature review did not include the early works. As we see in Thomas et al. (1973), the field was already well established over twenty years ago with highly evolved research involving indicators at the cellular, organismal, and community levels. The move toward bioindicators not only not solved the environmental effect problem, it also addressed the problem of static measurements in a dynamic system (Dickson et al. 1980).

Although bioindicators gave the advantage of integrating many environmental factors over long periods of time, early use was limited because results were not quantifiable and thus could not be used as a basis for remedial action (James and Evison 1979). This early critique might have been the challenge that directed the some of the research trends detailed in the next section. Today, the concept of bioindicators has an almost universal acceptance in the literature.

One strength of the general bioindicator literature is the fairly regular conceptual reviews and evaluations. These include Laughlin (1986), Lower and Kendall (1990), McCarthy and Shugart (1990), and Funke (1993). Ellis (1991), in a simple yet elegant experiment, gives a perfect example of the efficacy of bioindicators in describing how bioindicators can be used to detect environmental contaminants that would be extremely costly under a direct measurement program. These papers show that there is still wide support for the bioindicator model of determining environmental quality.

The bioindicator field has developed two large and specialized components involving either benthic organisms and sediments, or bivalve molluscs. Because these groups are so large,

they will each be treated in their own separate chapters: Chapter 4 for bivalves and Chapter 5 for benthic organisms. Other, less common examples of bioindicators include unicellular organisms (e.g., bacteria (Plusquellec et al. 1991) and microalgae (Gilbert et al. 1992)), macroalgae (Ho 1990) and seagrasses (Dennison et al. 1993), and animals as single individuals, e.g. fish (Jacobsson et al. 1986 and Rodgers et al. 1990), or as populations or communities (see Funke 1993)

3.2.1 Efficacy, Reviews and Evaluations

James, A. 1979. The Value of Biological Indicators in Relation to other Parameters of Water Quality. Chapter 1 in: *Biological Indicators of Water Quality*. A. James and Lillian Evison eds. John Wiley and Sons Ltd. New York.

> ABSTRACT: Water quality needs to be defined in relation to the use for which the water is required. The value of biological indicators needs to be judged on a similar basis. In reviewing the value of biological indicators some general points emerge. The most striking of these is the relative neglect of biological compared with chemical methods of assessment. Since water pollution is in many instances a biological phenomenon, it would appear logical that it ought to be measured biologically. This may be due in part to a lack of understanding of biological data but in many cases it is due to the non-quantitative nature of much of the information. For example in the case of organic pollution, if a stream with a standard of 4 mg/l for BOD has a concentration of 8 mg/l then the BOD load must be halved. But a Trent Index of V, when a standard of VIII is required, does not provide the same basis for remedial action. Another general point is the tendency to regard biological and chemical methods of assessment as alternatives. This view does not take account of the different kinds of information that they provide. Biological indicators show the degree of ecological imbalance that has been caused and chemical methods measure the concentration of pollutant(s) responsible. Both types of assessment are therefore necessary. (edited author abstract)
>
> ANNOTATION: Note that one of the authors points parallel one of the problems detailed in the Perception section; that water quality definitions should consider the use for which the water is intended.

Thomas, W. A.; Wilcoa, W. H.; Goldstein, G. 1973. *Biological indicators of environmental quality. A bibliography of abstracts.* Ann Arbor Science Publishers Inc., Ann Arbor.

> ABSTRACT: An extensive bibliography is provided on the subject of biological indicators. The selected abstracts emphasize the practical aspects of interpreting the biological manifestations of deteriorated environmental conditions and are organized so that users can focus their attention at any level of biological organization. (Edited abstract).
>
> ANNOTATION: The abstracts are organized into chapters based on the level of biological organization, and include molecular and cellular indicators, individual plant

and animal indicators, and finally, community level indicators which include biotic indices, diversity indices, and saprobic indices.

Dickson, Kenneth L., David Gruber, Christine King, and Kenneth Lubenski. 1980. Biological Monitoring to Provide an Early Warning of Environmental Contaminants. in: *Biological monitoring for environmental effects*. Douglas L. Worf, ed. D.C. Heath and Co.

ABSTRACT: Biological monitoring approaches have at least two uses in protecting aquatic ecosystems from damage from potentially hazardous chemical substances. First, the responses of aquatic organisms upon exposure to a chemical substance can be used to estimate the hazards associated with the use of the chemical substance. Second, biological monitoring systems can be used to continuously monitor the quality of the aquatic ecosystem and detect the presence of harmful environmental contaminants. By using information on the environmental fate of a chemical substance along with data on its effects, an assessment of hazard can be established. The environment can then be protected by means of decisions to ban or limit the use of potentially hazardous materials. A description of the biological monitoring techniques under investigation by the authors is presented. Living organisms serve as indicators of environmental quality by monitoring the ventilatory behavior, activity, and locomotor behavior of fish.

3.2.2 Overviews and Evaluations

A. James and Lilian Evison eds. 1979. Biological indicators of water quality. John Wiley & Sons Ltd. New York.

ANNOTATION: Previous water quality assessments have relied upon chemical and physical techniques, to relative neglect of biological factors. This is surprising because in many cases, the aim is the preservation of biological amenities. Biological methods for assessing water quality have many advantages. For example they can integrate many different environmental factors over a long period of time. However, they suffer from disadvantages in failing to provide a numerical basis for remedial action (edited preface). This book provides a comprehensive review of the role of biological indicators in the assessment of water quality. If also offers a critique on the role of bioindicators and serves to warn researchers that it is not a panacea.

Laughlin, R.B.; Guard, H.E. 1986. Biomonitors: Practice and concepts. pp. 862-866 in: *Oceans '86 conference record: science engineering adventure. vol. 3. Monitoring Strategies Symposium*. Marine Technology Soc., Washington.

ABSTRACT: The usefulness of organisms as biomonitors of environmental quality has been demonstrated repeatedly during episodes of acute poisoning. Management goals now largely seek to avoid or mitigate these occurrences, concomitant with introduction of chemicals to the environment. Biomonitors have largely been adopted as sentinel organisms to warn of excess bioavailability of xenobiotics. Uptake and retention processes in any organisms, however, are only semi-passive, so that

metabolic processes may influence both concentration ranges over which accumulation occurs, and mechanisms controlling it.

Lower, W. R.; Kendall, R. J. 1990. Sentinel Species and Sentinel Bioassay. pp 309-331 in: *Biomarkers of Environmental Contamination.* Lewis Pub., Chelsea, Michigan.

ABSTRACT: Assessment of the toxic effects of environmental contamination and the development of biological early warning systems for appraisal of these toxic effects can be advanced by the use of sentinel species and sentinel bioassays. A sentinel species can be defined as any domestic or wild microorganism, plant or animal, that can be used as an indicator of exposure to and toxicity of a xenobiotic that can be used in assessing the impact on human and/or environmental health because of the organism's sensitivity, position in a community, likelihood of exposure, and geographic and ecological distribution or abundance. A sentinel species can be any organism or tissue of an organism that fulfills the need as a suitable subject upon which to perform bioassay and chemical analysis. The selection of organisms and changes in biological functions as sentinels can be made from currently used species and bioassays. In addition, an effort can be made to 'plan' a species and''plan' a bioassay by developing a list of desired characteristics for both, discuss these with knowledgeable colleagues and, in a purposeful manner, come up with a best-effort combination which will accomplish the desired biological monitoring. Fish have been used as indicators of environmental contamination, including fish from the Great Lakes, from Torch Lake, Michigan, from wastewater treatment ponds in Alabama, and from the Fox River in Illinois. Marine fish from Puget Sound, the Hudson River, and Boston Harbor have also been used as bioindicators. (Lantz-PTT)

McCarthy, John F, and Lee R. Shugart editors. 1990. *Biomarkers of Environmental Contamination.* CRC Press, Boca Raton.

ANNOTATION: Biological markers are measurements at the molecular, biochemical, or cellular level in either wild populations or in organisms experimentally controlled to determine exposure to toxic chemicals, and the magnitude of the organism's response to the contaminant. Biological markers measures in wild animals can directly contribute to detecting, quantifying, and understanding the significance of exposure to chemicals in the environment. (edited preface)

Funke, W. 1993. Animals as indicators of alterations of the environment--A survey. *Phytocoenologia* 23: 363-375.

ABSTRACT: Microorganisms, lower and higher plants, and animals (as single individuals, populations or as more or less complex communities) may in manifold ways, serve as indicators of natural and/or anthropogenic alterations of the environment, next to tests of most important physical and chemical factors of air, water and soil. Due to their far-reaching relationships animals are more depending than autotrophic plants on the conditions of habitat, including food and other living compounds of ecosystems. Therefore they are also responding to influences which cause alterations

on other organisms. Further, animals are generally very mobile; metazoans possess sense organs and nervous systems and all of them display behaviour. By this, they register not only alterations of air, water, soil, and food, but also of optic, acoustic, olfactoric, and - partly - of electromagnetic patterns of stimulations of their surroundings. They respond to manipulations of the structure and function of landscape, on the decrease of their living space, on noise molestations etc. For animals with special demands on space and structure of their habitat changes of vital conditions will cause a decrease of fertility and/or an increase of emigration, and result in both, a decline of population density, and after all a decline of species numbers. Substantial pollutions, caused not only by industry and traffic, but also by agriculture and forestry, e.g. by excessive use of fertilizers or lime-depositing, and pesticides, will have the same effect. Toxic substances are often accumulated within food chains. This causes grave damages of health and even death, particularly in vertebrates. Thus animals will respond to a lot of influences and alterations esp. made by mankind. This is of fundamental interest. However for indication of a single stress factor less specialized responses are of rather considerable disadvantage. Investigations in full details are necessary in order to reach certain conclusions. In a rising manner this has already been done with marine, fresh-water and terrestrial animal species of various systematic and trophic groups. In a short survey the suitability of bioindication by animals is represented. Thereby it was differentiated at first between sensitive (or reactive) and accumulative bioindicators and secondly between aquatic and terrestrial species (or communities) or rather between indicators of toxic elements and dangerous organic substances.

Ellis, D. V. 1991. New Dangerous Chemicals in the Environment: Lessons from TBT. *Marine Pollution Bulletin* 22(1): 8-10.

ABSTRACT: Tributyltin (TBT), a broad spectrum pesticide, was introduced into the marine environment in boat antifouling paints and on salmon farm pen nets. Its use resulted in oyster farm losses, and it was found to accumulate in salmon and enter the human food chain. Measurement of TBT at (toxic) ppb levels requires expensive instruments and skilled operators. However, there is a biological indicator that is cheap to measure, requires little instrumentation, only basic anatomical dissection and observational skills, and is quick. This is **imposex**, the imposition of male characters on females. The response has been induced experimentally by TBT bioassays. The measurement technique has been refined so that it is now applicable routinely to neogastropod mollusks, which are easily collected, abundant, and globally distributed. Imposex has many qualities of good biological indicators, providing a quick, low precision surrogate measure of an environmental parameter. Because it can be applied easily, it can be used to indicate where the more expensive and time-consuming direct chemical measures should be made for the suspected toxin.

3.2.3 Examples

Plusquellec, A.; Beucher, M.; Le Lay, C.; Le Gal, Y.; Cleret J.J. 1991. Quantitative and qualitative bacteriology of the marine water surface microlayer in a sewage-polluted area. *Mar. Environ. Res.* 31(3): 227-239.

> ABSTRACT: This thin microlayer constituted of organic matter which is present at the sea-air interface has been shown to accumulate bacteria and, therefore, represents a phenomenon of sanitary significance. The enrichment of **indicator bacteria** observed within the neuston, in relation to subsurface water contamination, has been followed in three stations presenting different contamination levels and various types of pollution. The bacterial enrichment in the neuston has been estimated to range from 24- to 720-fold in comparison with subsurface water. For a given sampling station the enrichment observed for the four bacterial groups considered is rather homogeneous. In contrast, clear differences appear between the stations.

Gilbert, F.; Galgani, F.; Cadiou, Y. 1992. Rapid assessment of metabolic activity in marine microalgae: Application in ecotoxicological tests and evaluation of water quality. *Mar. Biol.* 112(2): 199-205.

> ABSTRACT:: A new method for the assessment of the effects of several contaminants on **marine microalgae**, *Tetraselmis suecica* (Kyling) Butcher, *Skeletonema costatum* (Grev.) Cleve, and *Prorocentrum lima* (Ehrenberg) Dodge was developed in 1990. The method is based on the measurement of cell esterase activity using a fluorimetric stain, fluorescein diacetate (FDA), selected from amongst three stains (FDA, Neutral Red, thiazolyl tetrazolium bromure) for its higher sensitivity. Biochemical (K sub(m), V sub(max)) and physiological (growth, specific activity) aspects of the enzymatic activity as revealed by the FDA method are discussed. Different categories of compounds (weed-killers, insecticides, metals) and some water samples from Seine Bay were tested for their toxic effects on microalgae. Experiments were performed on microplates using a fluorimetric microplate reader. The various steps of the experiments and data-processing were controlled by software. Applications of the system to rapid ecotoxicological tests (determination of the IC sub(50), i.e., the concentration at which 50% inhibition of growth occurs) and to the assessment of environment quality by studying the toxic effect of water samples on microalgae are proposed.

Ho, Y.B. 1990. *Ulva lactuca* as bioindicator of metal contamination in intertidal waters in Hong Kong. *Hydrobiologia* 203(1-2): 73-81.

> ABSTRACT: The use of ***Ulva lactuca*** as an indicator of metal contamination was assessed by analyzing the levels of Mn, Fe, Ni, Cu, Zn, Cd and Pb in the alga collected from 24 intertidal sites around the Island of Hong Kong. Twelve of the sites are in the rural southern part of the Island where the coastal waters are relatively clean. The remaining 12 sites are located in the north and within Victoria Harbour which receives, apart from industrial effluents, untreated domestic sewage from a population of some 3.5 million. The mean levels of Mn, Fe, Ni, Cu, Zn and Pb in

Ulva from the urban sites were respectively 4.0, 4.6, 1.8, 2.3, 2.4 and 4.6 folds those from the rural sites. However, similar levels of Cd were found in the alga amongst all the sites. Locations of high levels of metal contamination, particularly to the eastern end of the Harbour, have been identified. Preliminary results indicate that *Ulva* is a good indicator of Mn, Fe, Cu, Zn and Pb contaminations.

Dinnison, William C., Robert J. Orth, Kenneth A. Moore, J. Court Stevenson, Virginia Carter, Stan Kollar, Peter W. Bergstrom, and Richard A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *Bioscience* 43(2): 86-94.

ANNOTATION: A mechanism for relating anthropogenic inputs to the health of Chesapeake Bay is through determination of relationships among water quality and various living resources. The authors used the habitat requirements of **submerged aquatic vegetation** because of their widespread distribution, important ecological role, and sensitivity to water quality parameters such as chlorophyll a, dissolved inorganic phosphorous, light attenuation, total suspended solids, and dissolved inorganic nitrogen.

Jacobsson, A.; Neuman, E.; Thoresson, G. 1986. The viviparous blenny as an indicator of environmental effects of harmful substances. *Ambio.* 15(4): 236-238.

ABSTRACT: The **viviparous blenny** (*Zoarces viviparus*) seems to have properties necessary for indicating environmental effects of harmful substances. It has two main advantages over most other marine fishes: it is stationary during its life-span and the hatched fry live within the mother for several months. It was established that pregnant females are suitable for laboratory experiments and that exposure to a pulp mill effluent at concentrations which did not affect the survival of the mothers caused mortality and reduced growth of fry.

Rogers, I.H.; Birtwell, I.K.; Kruzynski, G.M. 1990. The Pacific eulachon (*Thaleichthys pacificus*) as a pollution indicator organism in the Fraser River estuary, Vancouver, British Columbia. *Sci. Total Environ.* 97-98: 713-727.

ABSTRACT: **Eulachons** (*Thaleichthys pacificus*) return to the Fraser River, British Columbia, Canada, each spring and migrate through the estuary to spawn in freshwater. During this migration they may be subjected to varying water quality conditions due to the discharge of domestic and industrial wastes and land drainage. Fish were captured at five estuarine stations in April 1986 and again at three stations in April/May 1988. Whole fish also contained DDE and DDD, while PCBs were present in some fish gonads in 1986, but not in 1988. With the exception of whole body concentrations of 2,3,4,6-tetrachlorophenol, concentrations of pentachlorophenol, 3,4,5-trichloroguaiacol, tetrachloroguaiacol, DDE and DDD in whole bodies, livers and gonads revealed an increasing trend with distance of the eulachon capture site upstream from the Fraser River mouth. Marked differences occurred in the concentration of contaminants in eulachon livers. The relatively high lipid content of eulachons

suggests them to be potential integrators of low-level contaminants in the Fraser River system.

3.3 Research Trends

Recent research has focused on the finer points of determining which behavior, morphology, fitness, or community structure of organisms makes the best site-specific or contaminant-specific indicator.

The first group of papers focuses on improving or fine tuning the bioindicator model. For example, Sinderman (1988) looked at the biological effects of contaminants to identify why certain organisms make good bioindicators, while Clark (1989) performed extensive tests on caged animals and judged the efficacy of various bioindicator approaches. Similarly, Adams (1990) reviewed and judged the efficacy of several methods that made assessments of stress on fish. In a more specialized paper, Quintero and Diaz (1994) show how bioindicators can be used to detect specific contaminants, e.g., aliphatic hydrocarbons.

The second group offers some general criticisms about bioindicators. Puccia (1983) notes that while the single species bioindicator model is more quantitative, it can give false results due to community interactions such as competitive dominance, and therefore recommends using the qualitative measure of community analysis. In a more specialized criticism, Landres et al. (1988) contends that vertebrates do not make effective or credible ecological indicators. This paper represents the group debating for or against certain types of bioindicators. Long and Chapman (1985) was the most critical paper found, but their critique only argued that bioindicators should be used as a part (albeit an important part) of a larger monitoring scheme which include measures of sediment contamination and toxicity. However, none of these critiques reject the general concept of bioindicators.

The third group answers the need for a qualitative measure, but they also take a more ecological tack. Bechtel and Copeland (1970) note that an effect of estuarine pollution is a change in the structure of all trophic levels, and thus the entire estuarine community. They therefore utilized a fish species diversity index as an indicator of environmental stress. Swartz (1972) reviews several indicators of environmental disturbance including population dynamics, community structure, and community metabolism. More recently, is Fausch et al. (1990) who call for using an index of biotic integrity, a more complex approach.

Finally, there is the emerging field of biodivirsity. Biodiversity has become both a national and international issue, but there has been less attention paid to biodiversity loss in marine and coastal ecosystems (Beatley 1991 and Wieting 1991). Moreover, the evidence suggests that serious losses will occur in estuarine fish (Moyle and Leidy 1991). DeFreese (1991) found threats to the biodivirsity of estuarine ecosystems of Florida, and noted that coastal zone management programs do not address biodivirsity loss. Unfortunately, the concept of

biodiversity does not yet provide a meaningful measure of environmental quality.[2] The biodivirsity literature is still in its descriptive stage and researchers have yet develop a quantitative measure to evaluate biodiversity.[3] Managers, therefore, cannot know what constitutes an acceptable condition of biodiversity.

3.3.1 Fine tuning the bioindicators model

Sindermann, C. J. 1988. Biological Indicators and Biological Effects of Estuarine/ Coastal Pollution. *Water Resources Bulletin* 24(5): 931-939.

> ABSTRACT: Sustained interest in and concern about the health status of the aquatic environment has resulted in extensive research focused on (1) effects of pollution on survival, growth, and reproduction of resource species at all life stages; (2) diseases of fish and shellfish, as they may be related to pollution and as they may serve as indicators of environmental stress; and (3) contaminant body burdens in fish and shellfish--their effects on the aquatic animals and their potential effects on humans. Effects, lethal and sublethal, of pollutants on life history stages of fish and shellfish have been documented, as have impacts on local stocks in badly degraded habitats, but as yet there has been no adequate quantitative demonstration of effects on entire aquatic species--probably because of the difficulty in sorting out relative effects of the many environmental factors that influence abundance. Sublethal effects, especially those that result in disease, have been examined intensively, and some diseases and disease syndromes have been associated statistically with pollution. Other pollution indicators (biochemical, physiological, genetic, behavioral, and ecological) have also received some attention, as have body burdens of contaminants in aquatic species. Research, especially that conducted during the past decade, has done much to clarify the many pathways and toxic effects of contaminants on aquatic animals, and has also helped to identify mechanisms for survival of fish and shellfish in the presence of environmental changes caused by human activities.

---

[2] *Global Marine Biological Diversity* (Elliot A. Norse, 1993, Island Press, Washington) provides a thorough and well written discussion of marine biological diversity, threats to biodivirsity, impediments to and tools for conservation, and specific recommendations for implementing an action plan. No quantitative definition of biodivirsity is provided, but this book was written for a nontechnical audience.

[3] The ecological and biostatistics literature includes a number of measures of diversity, some developed in the 1940s. These 'diversity indices' require specific census data for all the species contributing to the regional diversity. On the scale of a small plot of land, these diversity indices are quite practical. On the scale of an entire estuary, they have immense and impractical demands for census data.

Clark, J.R. 1989. Field studies in estuarine ecosystems: A review of approaches for assessing contaminant effects. pp. 120-133 in: *Aquatic toxicology and hazard assessment: 12th volume.* Cowgill, U.M.;Williams, L.R. eds.

ABSTRACT: A sampling strategy designed around contaminant source (agricultural runoff, direct discharge) and fate (solubles, particulates, sediments) and the hydrodynamics of the system studied is required to characterize the exposure of estuarine biota to contaminants. Field data obtained on contaminant effects should be applicable to risk assessment in order to verify approaches to predicting contaminant fate and effects in estuarine systems. Survival of caged test animals at field test sites provides data for direct comparison with laboratory toxicity test results. Coupling survival and other effects data from caged animal studies with assessments of stocks and dynamics of populations of the same or a related species at the field site may allow extrapolation from simple laboratory and field test results (acute or chronic) to more complex and ecologically significant endpoints.

Adams, S. Marshall. 1990. Status and Use of Biological Indicators for Evaluating the Effects of Stress on Fish. *Biological indicators of stress in fish. American Fisheries Society Symposium* 8:1-8. Adams, S.M., Ed.

ABSTRACT: Laboratory bioassays and other conventional methods of assessing stress on aquatic organisms generally lack ecological realism because of the many environmental factors that can influence stress responses at all levels of biological organization. The biological indicator approach involves measurement of a suite of selected stress responses at several levels of biological organization to assess sub lethal stress effects on fish. to give early warning of stress, and to obtain insights into causal relationships between stressors and effects manifested at higher levels of biological organization. The types of stress responses measured range from those at the subcellular and biochemical levels to those at the ecosystem level: the responses segregate along gradients of toxicological and ecological relevance and of response time. Companion papers in this volume survey the known indicators of stress at each level of organization and assess their practical uses for evaluation and prediction of chronic stress effects on fish populations and communities.

Quintero, S.; Diaz, C. 1994. Aliphatic hydrocarbons in fish from the Canary Islands. *Mar. Pollut. Bull.* 28(1): 44-49.

ABSTRACT: A major fraction of petroleum consists of aliphatic hydrocarbons, which may be used to detect the presence of oil in the aquatic environment. In this paper, the aliphatic hydrocarbon concentrations found in 56 samples of three fish species (*Boops boops*, *Scomber japonicus*, and *Sardina pilchardus*) are reported, in order to evaluate the local petrogenic and pyrogenic contamination.

3.3.2 Critiques and improvements

Puccia, Charles J. 1983. Qualitative Models for Marine Environmental Assessment. p 1 in: *Coastal Zone '83: Proceedings of the third symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: To understand the potential use of qualitative analysis in environmental impact assessment to marine habitats six models for benthic and intertidal habitats are described. These cases illustrate that (1) a species or functional group may be buffered from an impact because of the community structure; (2) competitors can be either positively or negatively correlated depending on point of entry of an impact; (3) changes in substrate composition may modify biotic interactions and the community response to environmental perturbation; (4) under certain conditions a locally confined community may be stable while the widespread community is unstable; (5) longer pathways from impact to functional group may dictate the affect of an impact, while direct or shorter paths have no affect; (6) for nonequilibrium communities the correlation between an organism and recruitment of settling larvae will be a function of the rest of the system in addition to the average abundance of adult and juvenile organisms.
>
> ANNOTATION: The interconnectedness between species form the community structure, and determine how an impact will be manifested. Since impacts can differ between each of the different models, reliance of the more quantitative single species approach can give misleading results. The author suggests that a qualitative analysis can be important to an environmental impact analysis.

Landres, P.B.; Verner, J.; Thomas, J.W.Ecological uses of vertebrate indicator species: A critique. 1988. *Conserv. Biol.* 2(4): 316-329.

> ABSTRACT: Plant and animal species have been used for decades as indicators of air and water quality and agricultural and range conditions. Increasingly, vertebrates are used to assess population trends and habitat quality for other species. In this paper the authors review the conceptual bases, assumptions, and published guidelines for selection and use of vertebrates as ecological indicators. The authors conclude that an absence of precise definitions and procedures, confounded criteria used to select species, and discordance with ecological literature severely weaken the effectiveness and credibility of using vertebrates as ecological indicators.
>
> ANNOTATION: One of the problems with vertebrates as indicators is their mobility. Contaminant levels in vertebrates may result from exposure in a different location rather than being related to the contaminant levels at the test site.

Long, E. R.; Chapman, M. P. 1985. A sediment quality triad: Measures of sediment contamination, toxicity and infaunal community composition in Puget Sound. *Mar. Pollut. Bull.* 16(10): 405-415.

> ABSTRACT: The purpose of this study was to determine the correspondence among measures of the three components of the Triad, using available data from several studies of Puget Sound. Good overall correspondence among the three components of the Triad was observed, based upon a comparison of average values from urban and rural portions of the Sound. However, based upon comparison of data on a station-by-station basis the chemical data alone were not always reliable indicators of biological effects.

3.3.3 Quantitative and Community models

Bechtel, Timothy J.; Copeland, B. J. 1970. Fish species diversity indices as indicators of pollution in Galveston Bay Texas. *Contributions in Marine Science* 15: 103-132.

> ABSTRACT: Fish species diversity indices calculated from trawl collections were useful indicators of environmental stress in Galveston Bay, Texas. Diversity values ranged from 2.2 in the Texas city-Galveston area to 0.02 in the Houston ship channel. Thus it is demonstrated that the concept of using species diversity to indicate adverse water quality conditions is applicable to the higher tropic levels of an estuary. Significant areal and seasonal differences were detected. It was also indicated that both biomass and numbers of organisms should be utilized when studying the diversity of higher tropic levels. Those areas receiving the greatest amounts of effluents and toxic materials (up to 86% effluent by volume) exhibited the lowest mean annual diversities. Fish populations could be divided into somewhat separate communities, each structured as a response to environmental and pollution stress. In those areas receiving the greatest stress, the bay anchovy, *Anchoa mitchille*, was the dominant species. These areas also supported the fewest numbers of large individuals. (Legore Washington)

Swartz, R. C. 1972. Biological criteria of environmental change in the Chesapeake Bay. *Chesapeake Science* 13 (Supplement): S17-S41.

> ABSTRACT: Biological phenomena in the Chesapeake Bay are exceptionally complex. Simple, unequivocal standards for characterizing biotic conditions are not available. A review of techniques for the determination of direction and rate of change of conditions in the bay is provided. Specific bioassays and their applicability to situations in the bay are discussed. **Condition indices, population dynamics, community structure, and community metabolism** are also sensitive indicators of environmental disturbance. For the immediate future it is desirable to rely upon several different procedures to document biological changes. The method selected will depend upon the habitat, season, and nature of the environmental alteration.

Kurt D. Fausch, John Lyons, James Karr, Paul L. Angermeier. 1990. *Fish Communities as Indicators of Environmental Degradation. Biological indicators of stress in fish. American Fisheries Society Symposium* 8:1-8. Adams, S.M., Ed.

ABSTRACT: The basis for using biological monitoring of fishes to assess environmental degradation is that the relative health of a fish community is a sensitive indicator of direct and indirect stresses on the entire aquatic ecosystem. The most common approaches to such assessment of environmental degradation involve use of (1) **indicator taxa or guilds**; (2) **indices of species richness, diversity, and evenness**; (3) multivariate methods; and (4) the **index of biotic integrity (IBI)**. The disadvantages of these methods are that they are quantitatively complex, few standard procedures exist, samples used to calculate multivariate results define the multivariate space, and results can be artifacts of the procedures or data used. The IBI is a composite index that integrates attributes of communities, populations, and individual organisms to assess biological integrity on the basis of accurate measures of relative abundance. Its main advantages are that it is a broadly based ecological index, it is sensitive to different sources of degradation, and it produces biologically meaningful and reproducible results when applied by competent fish biologists. Its disadvantages are that its application requires at least moderate species richness and extensive background information and that methods for setting some criteria are subjective. It also must be modified for different ecological regions, but modifications so far have retained the original ecological framework. Future research in biological monitoring by means of fish communities should focus on (1) standardization of methods of sampling and data analysis; (2) documentation of natural variation in fish communities, against which changes due to degradation can be compared; and (3) experimental manipulation to test assumptions underpinning all the indices. (edited author abstract)

3.3.4 Biodiversity

Beatley, T. 1991. Protecting biodiversity in coastal environments: Introduction and overview. *Coastal Management* 19(1): 1-19.

ABSTRACT: Much less attention has been paid in recent years to the threats to coastal and marine biodiversity, compared to biodiversity in more terrestrial habitats. The tremendous biodiversity at risk and the severity and magnitude of the pressures being exerted on coastal habitats suggest the need for much greater attention to be focused here by both the policy and scientific communities. The threats to coastal biodiversity are numerous and include air and water pollution; over exploitation and harvesting; the introduction of exotic species; the dramatic loss of habitat due to urbanization, agricultural expansion, and other land use changes; and the potentially serious effects of global climate change. These threats suggest the need for swift action at a number of jurisdictional and governmental levels. Major components of such an effort are identified and described.

Wieting, Donna S. 1991. Environmental impact assessment and the conservation of marine biological diversity. pp 330-341 in: *Coastal Zone: Proceedings of the Symposium on Coastal and Ocean Management v 1.* American Society of Civil Engineers, New York.

> AB: Legislation is pending to include assessment of biodiversity in the Environmental Impact Statement process and revise the National Environmental Policy Act to better address the conservation of biological diversity. The loss of biological diversity has become a critical issue both nationally and internationally, with the focus on destruction of tropical forests and the extinction of terrestrial species. Little attention has been given to the loss of biodiversity in other endangered systems, particularly the oceans and coastal waters. The goal of this paper is to discuss the environmental assessment process of NEPA as a means to conserve marine biological diversity. (Author abstract) 20 Refs.

Moyle, P.B.; Leidy, R.A. 1992. Loss of biodiversity in aquatic ecosystems: Evidence from fish faunas. Conservation biology. pp. 127-169 in: *The theory and practice of nature conservation, preservation, and management.* Fiedler, P.L.;Jain, S.K. eds.

> ABSTRACT: Fishes are appropriate indicators of trends in aquatic biodiversity because their enormous variety reflects a wide range of environmental conditions. Fish also have a major impact on the distribution and abundance of other organisms in waters they inhabit. Examination of trends in freshwater fish faunas from different parts of the world indicate that most faunas are in serious decline and in need of immediate protection. Species most likely to be threatened with immediate extinction are either specialized for life in large rivers or are endemic species with very small distributions. We conservatively estimate that 20% of the freshwater fish species of the world (ca. 1800 species) are already extinct or in serious decline. Evidence for serious declines in marine fishes is limited largely to estuarine fishes, reflecting their dependence on freshwater inflows, or to fishes in inland seas.

De Freese, D.E. 1991. Threats to biological diversity in marine and estuarine ecosystems of Florida. *Coastal Management* 19(1): 73-101.

> ABSTRACT: The Indian River Lagoon of east central Florida and the marine ecosystem of the Florida Keys are important natural ecosystems with ecological, economic, aesthetic, and recreational values. Both ecosystems have high biological diversity and are threatened by a variety of anthropogenic impacts. Although all coastal marine and estuarine ecosystems are influenced by an interplay of oceanic and terrestrial influences, structural and functional characteristics and anthropogenic impacts are often site-specific. Although Florida has enacted a framework of coastal zone management legislation, no legislation has specifically addressed the issue of biological diversity conservation in marine and estuarine ecosystems.

4. Bivalves

The largest group of papers found in this literature review addressed bivalves: clams and oysters, but especially mussels. Part of this group's attraction is their sessile nature. This helps assure researchers and managers that the contaminants absorbed came from the study site. Another is their wide distribution which is important for experimental reproducibility at different locations. The most important trait is that as filter feeders, they are able to accumulate and concentrate environmental contaminants to concentrations far above the ambient environmental level. Contaminants which occur below the threshold of detection in the environment, can more easily be detected using bioassays. One of the more commonly cited programs utilizes mussels in regional, national, and even global monitoring programs. They are referred to as Mussel Watch or Mussel Watch type programs and are distinct enough to merit own section.

The efficacy of using bivalves as bioindicators is long established, thus we did not pursue the early research for this literature review. Still, Costa (1989) provides a list of criteria for good sentinel organisms, and some reasons why mussels would make a good choice. He also offeres a methodology to optimize the use of *Mytilus spp.* an a quantitative indicator of cadmium and mercury contamination.

Other examples of bivalves as a bioindicators had a similar theme: the efficacy of bivalves as indicators were either assumed or briefly reviewed, followed by a detailed, contaminant-specific report on bivalves (usually mussels) as the indicator. Although these papers use the term 'biological indicator,' their methodology is too contaminant-specific to necessarily be useful for our purpose: a larger scale indicator of environmental quality. They are mentioned here to show the degree of sophistication in the research, and because some of the specific tests may be relevant to one aspect of an overall coastal zone quality measure. The contaminants include metals (Phillips 1976 and Fischer 1988), carcinogens (Couch et al. 1979), polynuclear aromatic hydrocarbons (Bender et al. 1986), polychlorinated dibenzo-p-dioxin (Miyata et al. 1987), and range of volatile compounds (Rasmussen et al. 1993)

Cossa, D. 1989. A review of the use of *Mytilus* spp. as quantitative indicators of cadmium and mercury contamination in coastal waters. *Oceanol. Acta.* 12(4): 417-432.

> ABSTRACT: The use of marine mussels to monitor cadmium and mercury contamination in coastal waters is reassessed on the basis of the current knowledge of metal metabolism in *Mytilus* spp. Sources and amplitude of variation of metal concentrations in the soft tissues of the mussel are described. Methods (sampling strategies and normalizations) for optimizing the use of *Mytilus* spp. as quantitative indicators of metal contamination are given. Some directions for further research are suggested.
>
> ANNOTATION: The author begins his review with a summary of the ideal attributes of a sentinel organism. These are: (i) it should accumulate contaminants; (ii) it should be sedentary; (iii) it should have more than a one year lifespan; (iv)it should provide

sufficient tissue for chemical analysis; (v) it should tolerate a wide salinity range; (vi) it should allow direct measurement without pre-concentration; (vii) tissue level contaminant should correlate with that in the surrounding waters; and (viii) the effects of variations in salinity and temperature are known. a long lifespan and of reasons why the mussel *Mytilus spp.* is a superior choice. (i) the genus is widespread; (ii) the animals are sessile; (iii) they accumulate contaminants with a concentration factor of 10^3 to 10^5; (iv) they are relatively resistant to pollution; (v) they can be transplanted; (vi) they are euryhaline; (vii) they are a potential source of contaminants in humans.

Phillips, D. J. H. 1976. The Common Mussel *Mytilus edulis* as an Indicator of Pollution by Zinc, Cadmium, Lead, and Copper. II. Relationship of Metals in the Mussel to Those Discharged by Industry. *Marine Biology* 38: 71-80.

ABSTRACT: Concentrations of zinc, cadmium, lead and copper were measured in whole soft parts of the common mussel *Mytilus* edulis to determine its potential as a bioindicator for trace metals. M. edulis was found to be an efficient time-integrated indicator of zinc, cadmium and lead over varied environmental conditions including changes in salinity, water temperature, relative metal concentrations, and depth and season of sampling. The mussel was recommended as an alternative indicator to sediment and water analysis and was suggested for the monitoring of industrial effluents at the discharge site, allowing rapid and inexpensive water quality control. Its use as an indicator for copper was discouraged.

Fischer, H. 1988. *Mytilus edulis* as a quantitative indicator of dissolved cadmium. Final study and synthesis. *Mar. Ecol. Prog. Ser.* 48(2): 163-174.

ABSTRACT: Juvenile blue mussels *Mytilus* edulis were cultivated in flow-through aquaria to investigate the influence of dissolved cadmium on cadmium accumulation (in terms of the Cd/shell-wt index). Where the ratio (by weight) of dissolved Zn to Cd remains within the range 25:1 to 60:1, accumulation of Cd is not significantly influenced by dissolved Zn. Higher levels of concomitant Zn reduce the Cd/shell-wt index. A lower ratio of Zn to Cd may slightly increase Cd accumulation. The Cd/shell-wt index is proportional to ambient levels of dissolved Cd up to 100 mu g/l. There were no significant effects on growth up to ca 30 mu g/l Cd. Results corresponded to earlier experimental work and to field surveillance data reported in the literature.

Couch, J.A.; Courtney, L.A.; Winstead, J.T.; Foss, S.S. 1979. The American oyster (*Crassostrea virginica*) as an indicator of carcinogens in the aquatic environment. pp. 65-84 in: *Animals as monitors of environmental pollutants. Symposium on pathobiology of environmental pollutants: animal models and wildlife as monitors.*

ABSTRACT: The American oyster (*C. virginica*) was used as the experimental animal for chronic exposure to 3-methylcholanthrene (3-MC) and benzo(a)pyrene (BP) in an exposure system in which the carcinogens can be continuously injected into free flowing water at fixed rates. Experiments showed that they are concentrated in oyster

tissues in direct proportion to the dosage of carcinogen injected into the system. Residual concentrations of MC and BP were present in oysters as long as 6 months following exposure. Aryl hydrocarbon hydroxylase (AHH) activity was present in homogenates of hepatopancreas after 5.5 months of exposure to the carcinogens, in contrast to control animals in which AHH activity was quite low.

Bender, M.E.; deFur, P.O.; Huggett, R.J. 1986.Polynuclear aromatic hydrocarbon monitoring in estuaries utilizing: Oysters, brackish water clams and sediments. pp 791-796 in: *Oceans '86 Conference record: Science Engineering Adventure. vol. 3. Monitoring Strategies Symposium*. Marine Technology Soc., Washington, DC; IEEE, New York.

ABSTRACT: The monitoring of contamination from polynuclear aromatic hydrocarbons (PAH) in estuarine animals is complicated by the necessity of utilizing different species as one progresses upstream along the salinity gradient. In the Chesapeake Bay, most tributary sub-estuaries contain two bivalve species, the oyster, Crassostrea virginica , and the brackish water clam, *Rangia cuneata*, which frequently have overlapping distributions. This paper describes the use of these species and sediments as monitors for PAH contamination in the James, York and Rappahannock rivers. Seasonal, species and source related differences are discussed.

Miyata, H.; Takayama, K.; Ogaki, J.; Kashimoto, T.; Fukushima, S. 1987. Polychlorinated dibenzo-p-dioxins in blue mussel from marine coastal water in Japan. *Bull. Environ. Contam. Toxicol.* 39(5): 877-883.

ABSTRACT: Polychlorinated dibenzo-p-dioxins (PCDDs) are tricyclic aromatic compounds containing 75 specific isomers. PCDDs have been revealed to generate as a by-product in the production process of chlorinated herbicides and in the combustion process of domestic and industrial wastes. In this paper, the pollution degree of PCDDs in marine coastal water in the authors' country was examined by using blue mussel, *Mytilus* edulis , as a biological indicator because it provided an effective trapping mechanism for many environmental pollutants.

Rasmussen, T.; Anthoni, U.; Christophersen, C.; Nielsen, P.H. 1993. Volatile compounds from the marine indicator organism *Mytilus edulis*. *Chemosphere* 27(11): 2123-2125.

ABSTRACT: The blue mussel, *Mytilus* edulis is widely used as an indicator organism to monitor the chemical conditions of the environment in which it thrives. Although volatile compounds relating to oil pollution and to pesticide contamination have been intensively investigated other volatiles have received only minor attention. This is unexpected owing to the economic importance of the flavor of commercial mussels and the importance of monitoring volatile contaminants. Conventional Likens-Nickerson gas phase extraction has revealed the potential of this organism to yield information, especially on short time variations in the chemical composition of the environment. Commercial samples of *Mytilus* edulis were extracted using a Likens-Nickerson extractor and analyzed gas chromatography and combined gas chromatography-mass spectrometry allowing characterization of 33 components. The method is

suited for the study of fluxes of volatile compounds including environmental contaminants in the sea.

4.1 Research Trends

In previous chapters, the "research trends" section summarizes the debate between researchers. Here we see similar patterns to those in the foregoing chapters—fine tuning, developing qualitative models, etc.

The first group of papers deals with fine tuning the use of bivalves as indicators. For example, Phillips (1976 and 1977) found that different environmental conditions, salinity and temperature, would lead to different levels of metal accumulation. But this was more than just a warning. Philips (1976) also devised and recommended using a sampling program that would eliminate the effects of those environmental variables. Phillips and Yim (1981) compared different species as indicators Looking for a more cost effective way to determine metal contamination, Imber et al. (1987) devised a simple method for quantifying metal-binding proteins.

The second group of papers addresses the quest for a more quantitative model. These models include a severity index (Lorda et al. 1981), total body water (Krieger et al. 1981), hemocyte concentrations (McCormick 1987), adenylate energy charge (Zaroogian and Johnson 1989), and the oyster condition index (Austin et al. 1993). While these models give quantifiable results, they are less useful as indicators of general environmental quality due to their expense.

The final group of papers reviewed or compared several different research models. For example, Phelps et al. (1981) confirmed the usefulness of scope for growth and gill-tissue oxygen consumption for indicating metabolic stress. In a more comprehensive evaluation, Small et al (1990) evaluated scope for growth, anoxic survival, lysosomal stability and gonad index in relation to the body's accumulated burden of contaminants. Again, these measures are not especially useful as environmental indicators, but do show the direction research has been moving.

4.1.1 Fine Tuning

Phillips, D. J. H. 1976. The Common Mussel *Mytilus edulis* as an Indicator of Pollution by Zinc, Cadmium, Lead and Copper. I. Effects of Environmental Variables on Uptake of Metals. *Marine Biology* 38: 56-69.

> ABSTRACT: The net uptake of zinc, cadmium, lead and copper by the common mussel, *Mytilus edulis* L. exposed to different conditions was investigated with a view to using this species as an indicator of contamination of the marine environment by these metals. Seasonal variation in concentrations of zinc, cadmium and copper was found in samples collected at three separate locations. The relationship of seasonal

variation to tissue weight and absorption route of the metals is discussed. Near to freshwater inputs of trace metals, the concentrations of zinc, cadmium and lead in mussels were found to vary according to the depth at which the mussels collected; in summer when freshwater run-off is less, this effect was absent. Low salinities did not affect the net uptake of zinc of lead. Low temperatures had no effect on the net uptake of zinc or lead; the net uptake of cadmium was unaffected by low temperatures at high salinities but was decreased by low temperatures at low salinities. The presence of the other metals had no effect on the individual net uptake of either zinc, cadmium or lead. A sampling program was devised to eliminate the effects of these environmental variables and to allow the use of M. edulis as an indicator of zinc, cadmium and lead in marine and estuarine environments. (EIS-Katz)

Phillips, D. J. H. 1977. Effects of Salinity on the Net Uptake of Zinc by the Common Mussel *Mytilus edulis*. *Marine Biology* 41: 79-88.

ABSTRACT: The net uptake of zinc by the common mussel *Mytilus* edulis (L.) has been investigated under different natural and artificial salinity stresses. The effects of stable and fluctuating salinities on the uptake of zinc by the mussel are discussed in terms of three possible modes of action. Under certain highly-stressful conditions, salinity may affect the uptake of zinc by the mussel. This factor should be considered when the mussel is used as an indicator of environmental pollution by zinc in estuarine areas, or spurious conclusions may result. (Katz)

Phillips, D.J.H.; Yim, W.W. S. 1981. A comparative evaluation of oysters, mussels and sediments as indicators of trace metals in Hong Kong waters. *Mar. Ecol. Prog. Ser.* 6(3): 285-293.

ABSTRACT: Oysters (*Saccostrea glomerata* = *Crassostrea glomerata* Gould) from the heavily urbanized Victoria Harbour area were contaminated by copper and zinc. Data for copper and zinc in sediments confirmed this finding. In addition, mussels (*Septifer bilocularis* (L.)) were collected. Copper concentrations in the mussels were in qualitative agreement with the profiles derived from oyster and sediment investigations. Zinc was regulated by the mussels to a much greater extent. The authors propose that *S. bilocularis* is unsuitable as an indicator organism of trace metals due to partial or complete metabolic regulation. Future studies in the tropics should be cognizant of this possibility when employing other previously unstudied bivalve species as bio-indicators.

Imber, B.E.; Thompson,-J.A.J.; Ward, S. 1987. Metal-binding protein in the Pacific oyster, *Crassostrea gigas*: Assessment of the protein as a biochemical environmental indicator. *Bull. Environ. Contam. Toxicol.* 38(4): 707-714.

ABSTRACT: The determination of metal-binding proteins in the Pacific Oyster (*Crassostrea gigas*) is reported. The objectives of this study were to employ a simple, cost-effective method for quantifying MBP and to assess this parameter for possible use as an indicator of identifiable sources of metal input to biological system.

4.1.2 Models

Lorda, E.; Walker, H.A.; Saila, S.B. 1981. A Severity Index to Assess and Monitor the Incidence of Pollution-Related Pathological Conditions in Marine Organisms. *Mar. Environ. Res.* 5(2): 93-108.

> ABSTRACT: A normalised matrix of the occurrences and co-occurrences of n-pathological conditions in a hypothetical population is termed a **severity matrix** and was used to define a volume in an n-dimensional vector space representing the severity or extent of the spread of the conditions in the population. The changes in this volume resulting from varying the numbers of occurrences and co-occurrences in the severity matrix are described by the varying determinant of the matrix. Actual data from a population of the soft-shell clam *Mya arenaria* were used to demonstrate the application of this methodology to characterize the incidence of five pathological conditions assumed to be indicators of pollution related stress on the clam population.

Krieger, R.I.; Gee, S.J.; Lim, L.O. 1981. Marine Bivalves, Particularly Mussels, *Mytilis* sp., for Assessment of Environmental Quality. *Ecotoxicol. Environ. Saf.* 5(1): 72-86

> ABSTRACT: Marine bivalves such as *Mytilus* sp,. are widely distributed, vigorous, relatively large, and a dominant species in coastal habitats. In addition their filter-feeding, and sessile adult behavior facilitate sampling of marine environments in studies of the distribution of heavy metals, radionuclides, petroleum hydrocarbons, and halogenated aromatic hydrocarbons. Studies have begun to determine whether **total body water** can be used as an indicator of stress. Antipyrine is a useful indicator for such studies since it is well tolerated and rapidly cleared by the mussels. This body water measurement represents a noninvasive condition index which may be valuable in long-term studies. Studies of the uptake, metabolism, and elimination of antipyrine and the chlorinated insecticide aldrin have shown that mussels have exidative metabolic capability. This result contrasts with findings of previous investigators and suggests that metabolism should be given careful evaluation in both chemical biological studies of effects of persistent environmental pollutants.

McCormick, Ray M. G. 1987. Hemocytes of *Mytilus edulis* Affected by Prudhoe Bay Crude Oil Emulsion. *Marine Environmental Research* 22(2): 107-122.

> ABSTRACT: Hemocytes and tissues of *Mytilus* edulis were examined after 4-5 or 8-9 weeks exposure to 390 micrograms/L or 740 micrograms/L Prudhoe Bay crude oil emulsion, during the animals' most metabolically active season. A reduction in **hemocytes** occurred in animals exposed to 740 micrograms/L after 4-5 weeks. After 8-9 weeks, hemocyte counts of both test groups increased, due to higher densities of granulocytes, yet the phagocytic response was reduced. Agranulocyte densities were reduced in animals exposed to 390 micrograms/L, due to lower counts of 2-3 micron agranulocytes. Adipogranular cell percentages in test animals were reduced. The initial reduction in granulocytes, their increases with time, and the reduced densities

of agranulocytes in mussels exposed to emulsion may be indicators of a general adaptive response to stress.

Zaroogian, G.E.; Johnson, M. 1989. Adenylate energy charge and adenine nucleotide measurements as indicators of stress in the mussel *Mytilus edulis*, treated with dredged material under laboratory conditions. *Bull. Environ. Contam. Toxicol.* 43(3): 428-435

ABSTRACT: **Adenylate energy charge (AEC)** is an indication of the amount of energy available to an organism from the adenylate pool. It is calculated from measured concentrations of three adenine nucleotides, adenosine triphosphate (ATP), adenosine diphosphate (ADP) and adenosine monophosphate (AMP), which are integral to the energy metabolism of all organisms. Accordingly, the objective of this study was to evaluate the applicability of AEC as a measure of stress in a filter feeder, the mussel *Mytilus* edulis , treated with dredged material under laboratory conditions and to determine the degree of variability inherent in the test.

Austin, H.; Haven, D.S.; Moustafa, M.S. 1993. The relationship between trends in a condition index of the American oyster, *Crassostrea virginica*, and environmental parameters in three Virginia estuaries. *Estuaries* 16(2): 362-374.

ABSTRACT: **Oyster Condition Index (CI)** was partitioned, using a moving average filter, into seasonal cycles and long-term trends in the James, York, and Rappahannock rivers for the period 1970-1983. Seasonal cyclic fluctuations in CI could be explained partially by changes in salinity and number of days within various temperature regimes. Long-term trends in the James River show a steady increase in CI over the study period, while a concurrent decline was noted in the Rappahannock River. Superimposed on these trends is a 4 to 5 yr cycle that is in synchrony with river discharge (salinity). In the York River, CI peaked in 1975-1976 at all stations. Measured environmental parameters do not sufficiently explain the trends. We speculate that the differences in the Rappahannock and James rivers may be due to a decline in **bottom oxygen** as a result of gravitational circulation differences.

4.1.3 Model Reviews

Phelps, D.K.; Galloway, W.; Thurberg, F.P.; Gould, E.; Dawson, M.A. 1981. Comparison of several physiological monitoring techniques as applied to the blue mussel, *Mytilus edulis* along a gradient of pollutant stress in Narrangarsett Bay, Rhode Island. pp. 335-355 in: *Biological Monitoring of Marine Pollutants*. Vernberg,-F.J.;Calabrese, A.;Thurberg, F.P.;Vernberg, W.B. eds.

ABSTRACT: Sublethal pollutant stress in mussels was clearly detected in a field-monitoring situation using these criteria of physiological response: **scope for growth, tissue residue analysis, and gill respiration and glycolytic rates** in either gill or posterior adductor muscle. Scope for growth and gill-tissue oxygen consumption are both valuable indices of metabolic stress in mussels. Examination of enzyme activity in mussel gill and posterior adductor muscle confirmed the results of gill-tissue

oxygen consumption and the scope for growth. **Hemolymph ion and adenylate energy charge measurements did not detect pollutant stress** in mussels held at the polluted field station of this study. The relative abundance of pinnotherid crab commensals were considered to be an interesting potential indicator of relative pollution in the field. Levels of nickel in *Mytilus* tissues were remarkably stable over a 3-year period, and both nickel and petroleum hydrocarbons reflected the stress gradient in Narragansett Bay.

Smaal, A.C.; Wagenvoort, A.; Hemelraad, J.; Akkerman, I. 1990. Response to stress of mussels exposed in Dutch tidal waters. *Physiological and biochemical approaches to the toxicolofical assessment of environmental pollution.* vp

ABSTRACT: The mussel *Mytilus* edulis is extensively used as an indicator of environmental pollution. The response to stress has been estimated by measuring a number of physiological, cytological and histological parameters in mussels from wild populations in the Western Scheldt, and in mussels that were transplanted from the Eastern Scheldt (clean reference site) to the Western Scheldt and to the Dutch coastal zone. **Scope for growth, anoxic survival, lysosomal stability and gonad index** are evaluated in relation to the body burden of a mixture of contaminants.

4.2 Mussel Watch

The term "Mussel Watch" was first introduced by Goldberg (1975). Although his paper was only a single page, it was an idea whose time had come. The idea of Mussel Watch was to use bivalves for monitoring contaminant concentrations, and as an indicator of contaminant bioavailability. Bivalves were chosen because of their worldwide distribution and ubiquitous abundance, their general ability to bioconcentrate most pollutants, and their sedentary habits.

The initial Mussel Watch program in the United States ran from 1976-1978. During those three years, mussels and oysters were sampled at 90 to 100 stations and tested for a variety of contaminants (Farrington et al. 1982). Afterwards, there were a series of evaluations. Goldberg et al. (1983) concluded that annual monitoring may not be necessary. In another review, Galloway et al. (1983) determined that the third year's protocol for sample preparation and quality control was far superior to those in the previous years. Goldberg (1986) again reviewed results from 1976-78, but this time, reiterated the need for a global mussel watch program. Finally, in a more critical vein Farrington et al. (1987), not only evaluated the 1976-1978 Mussel Watch program, but also a Mussel Watch-type program in the United Kingdom (1977-1970), and noted several limitations, among which were that bivalves were not always found where measurements were required and that bioaccumulation is affected by many biotic and abiotic factors.

In 1986, Mussel Watch became a permanent program. Excellent descriptions of this modern application are found in Freitas and Boehm (1989) and O'Connor (1992). A recent evaluation of the program highlighted some deficiencies, but was still very supportive of the program

(Bayne 1989). Other research supports the program by proposing methods to improve the efficacy of the model (Lobel 1991).

Mussel Watch may not be what Goldberg envisioned, i.e. it is not yet global, but it certainly has had an international scope. Following the 1976-1978 Mussel Watch program, Risebrough et al. (1983) applied the concept in Spain. After 1986, when Mussel Watch became a permanent program, the scope increased even more. Tavares et al. (1988) applied the Mussel Watch concept in Brazil to obtain, for the first time, monitoring data for the southwest Atlantic coast, and Martin (1991) describes how Mussel Watch became the most successful monitoring program in Australia.

Mussel Watch has been a success, so much so that other organizations and researchers have used Mussel Watch protocol in their own studies and have added their results to the mussel watch data base (Tureon and Lauenstein (1991) and Boudreau et al. (1993)). With such a strong background, Mussel Watch should be a part of the overall indicator of quality in the coastal zone. The only potential challenge is having the public accept it as a standard.

Goldberg, E.D. 1975. The Mussel Watch: A first step in global marine monitoring. Marine Pollution Bulletin 6(7): 111.

> ANNOTATION: Many global monitoring programs fail because of their vastness and complexity. Goldberg proposes using mussels at 100 coastal and open ocean sites to monitor, on an annual basis, the concentrations of halogenated hydrocarbons, transuranics, heavy metals, and petroleum.

Farrington, J.W.; Risebrough, R.W.; Parker, P.L.; Davis, A.C.; de Lappe, B. 1982. *Hydrocarbons, polychorinated biphenyls, and DDE in mussels and oysters from the U.S. coast -- 1976-1978 - the mussel watch.* La Jolla, California. 111 pp

> ABSTRACT: *Mytilus* edulis, *Mytilus californianus*, *Crassostrea virginica*, and *Ostrea equestris* were sampled at 90 to 100 stations around the United States coastline during each of three years -- 1976, 1977, 1978. Data for concentrations of PCB, DDE, total hydrocarbons, gas chromatographically unresolved complex mixture hydrocarbons, and selected aromatic hydrocarbons are presented for most of the samples.

Goldberg, E.D.; Koide,-M.; Hodge, V.; Flegal,-A.R.; Martin, J. 1983.U.S. Mussel Watch: 1977-1978 results on trace metals and radionuclides. *Estuar. Coast. Shelf Sci.*16(1): 69-93.

> ABSTRACT: The results of the U.S. Mussel Watch Monitoring Program for the period 1976-1978 for trace metals and artificial radionuclides in bivalves are presented. The substances analysed included Ag, Cu, Zn, Cd, Ni, Pb, super(238)Pu super(239+240)Pu and super(241)Am. The concentrations of these substances in the bivalves may reflect upwelling processes, anthropogenic inputs or natural levels. Off the California coast, mussels show markedly elevated Pu and Cd concentrations in coastal areas adjacent to the most intensive upwelling zones. Elevated levels of Pb,

for example, are found in organisms living adjacent to highly urbanized places. It is concluded that annual monitoring activities may not be necessary.

Galloway, W.B.; Lake, J.L.; Phelps, D.K.; Rogerson, P.F.; Bowen, V.T.; Farrington, J.W.; Goldberg,-E.D.; Lasetter, J.L.; Lawler, G.C.; et al. 1983. The mussel watch. Intercomparison of trace level constituent determinations. *Environ. Toxicol. Chem.* 2(4): 395-410.

ABSTRACT: The U.S. National Mussel Watch Program initially used split-sample analyses for interlaboratory quality control purposes. These indicated the possibility of interlaboratory analytical discrepancies as well as problems in the split-sample technique itself. For the third year of the program, two mussel homogenates were produced to serve as intercomparison samples - one for metals and organics, the others for radionuclides. The results obtained using these homogenates are encouraging in that generally good agreement is seen among analyzed done by several labs in diverse pollutant classes. The authors conclude from this experience that a quality control program relying on the analysis of large homogeneous samples of the matrix being dealt with is an essential part of any extensive, multilaboratory analytical program.

Goldberg, E.D. 1986. The Mussel Watch concept. *Integrated Global Ocean Monitoring* 7(1): 91-103.

ABSTRACT: The use of bivalves as sentinel organisms for collectives of marine pollutants is evaluated with data from the U.S. Mussel Watch, 1976-1978. The utilization of soft parts and of the shells are compared for metals and plutonium. Finally, the need for a global mussel watch, emphasizing the analyses of chlorinated hydrocarbon biocides in the tropics and southern hemisphere, is presented.

Farrington, J. W .; Davis, A. C.; Tripp, B. W.; Phelps, D. K.; Galloway, W. B. 1987. Mussel Watch: Measurements of Chemical Pollutants in Bivalves as One Indicator of Coastal Environmental Quality. pp 125-139 in: *New Approaches to Monitoring Aquatic Ecosystems.* American Society for Testing and Materials, Philadelphia.

ABSTRACT: The use of bivalves as bioindicators in monitoring for chemicals of environmental concern was evaluated by regional and national programs and by smaller scale research efforts in several countries during the past 15 years. Among the many programs was a Mussel Watch-type program in the United Kingdom waters in 1977-1978. Heavy metals, halogenated hydrocarbons, and fossil fuel hydrocarbons were measured. Evaluation of this program indicated that it successfully covered the area and contaminants of interest, that hot spots and clean or background areas were readily identified, and that some contaminants not revealed by previous monitoring programs were found. The U.S. Mussel Watch program, conducted during 1976-1978, monitored for heavy metals, transuranic radionuclides, fossil fuel hydrocarbons, and halogenated hydrocarbons. Very high concentrations of polychlorinated biphenyls were found in the New Bedford, Massachusetts area. Plutonium found in mussels

from the Oregon-California border south to Point Fermin was traced to upwelling of mid-depth waters from the Pacific Ocean containing fallout from nuclear weapons tests, not to radioactive waste dumped in the deep waters nearby. There are some limitations of the bivalve monitoring method. Concentrations of contaminants in bivalves and biological effects in these organisms cannot be extrapolated to the health of entire ecosystems. Body burdens of chemicals in bivalves cannot be extrapolated to effects on human health. Bivalves are not always found where measurements are required. Bioconcentration factors are not the same for all chemicals. Bioaccumulation is affected by many factors, such as reproductive stats, nutrition, temperature, and salinity.

4.2.1 Modern Mussel watch

Freitas, Sandra T.; Boehm, Paul D. 1989. Contaminant concentrations in bivalve molluscs from the U.S. Coastal Atlantic and Pacific. pp 3901-3915 in: *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: The NOAA Mussel Watch Project, one component of the National Status and Trends (NS&T) Program, is a marine monitoring program that measures the concentration of over 40 organic contaminants including polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), and pesticides; 13 trace and major metals; organotin compounds; and normalizing parameters (lipid content, TOC, etc.) in marine bivalves and surface sediments. Three years of data for contaminants in bivalve tissues have been generated at more than 100 Atlantic and Pacific coastal sites. Additionally, detailed histopathological observations on bivalves have been recorded at some sites. The data provide a comprehensive, national scale assessment of the levels of bioavailable contaminants in coastal waters and documentation of pathological abnormalities such as neoplasia.

O'Connor, Thomas P. 1992. Mussel Watch: *Recent trends in coastal environmental quality.* National Oceanic and Atmospheric Administration, Washington.

ANNOTATION: In 1984, the National Oceanic and Atmospheric Administration (NOAA) created the National Status and Trends (NS&T) Program. The program monitors trends of a broad suite of trace metals and organic chemical contamination and assesses the effects of human activities on coastal and estuarine areas around the nation. It had been analyzing estuarine and coastal sediments and tissue samples from selected organisms for a broad suite of trace metals and organic chemicals. Since 1986, the NOAA Mussel Watch Project, a major component of the NS&T Program, has been making the same chemical measurements on surface sediments and whole soft-parts of mussels and oysters collected from about 200 coastal and estuarine sites. Recent results from the Mussel Watch Project describe the spatial distribution of coastal contamination and, where temporal trends exist, show contamination to be decreasing in many instances. This finding implies that some benefits have resulted form the management of chemical use and discharge. However, data for more years will be

necessary to distinguish the effects of human activity from those of natural influences on some of these chemical concentrations.

Bayne, B.L. 1989. Measuring the biological effects of pollution: The Mussel Watch approach. *Water Sci. Technol.* 21(10-11): 1089-1100.

ABSTRACT: The Mussel Watch approach to environmental monitoring is briefly described and the potentials for various biological measurements to complement the normal practice of chemical determinations are discussed. Some of the available "biological effects techniques" are illustrated by reference to a recent practical workshop at which they were tested. Certain shortcomings in the approach are considered, but the conclusion reached that wider application of available biological techniques would benefit coastal environmental quality assessment.
AN: The "biological effects techniques" includes biochemical and cellular responses such as a metal-binding protein index and lysosomal stability, and physiological responses such as the scope for growth index. With these measures, the Mussel Watch program can obtain information on the cellular and sub-cellular level and at the organismal level. The shortcoming is that Mussel Watch cannot provide information at the community level, which is the main focus of concern. Therefore, the Mussel Watch concept cannot, by itself, yield information convincing enough to support legislative action.

Lobel,-P.B.; Bajdik,-C.D.; Belkhode,-S.P.; Jackson,-S.E.; Longerich,-H.P. 1991. Improved protocol for collecting Mussel Watch specimens taking into account sex, size, condition, shell shape, and chronological age. *Arch. Environ. Contam. Toxicol.* 21(3): 409-414.

ABSTRACT: This study was done to determine the relative effects of five variables (sex, soft tissue dry weight, condition index, width:height ratio, chronological age) on the concentration of 24 elements in the blue mussel *Mytilus* edulis and to develop an improved protocol for collecting mussels for biological monitoring programs. The five explanatory variables were treated as independent variables in multiple regression equation with the individual element concentrations being included as the dependent variable. A multivariate test was also performed. An initial test showed that chronological age per se had no significant effect on the concentrations of any of the elements; therefore, it was dropped from the equation. Condition index and soft tissue dry weight showed a high degree of negative association with element concentrations. This was explained as being due to growth rate differences (dilution effect). An improved condition index is suggested. Sex was also a major factor in determining element concentrations with the greatest effects being noted for manganese, copper, arsenic, and selenium (females greater than males).

4.2.2 Application of Mussel Watch

Risebrough, R.W.; Lappe, B.W. De; Walker, W.,II; Simoneit, B.T.; Grimalt, J.; Albaiges, J.; Regueiro, J. 1983. Application of the Mussel Watch concept in studies of the distribution of hydrocarbons in the coastal zone of the Ebro Delta. *Mar. Pollut. Bull.* 14(5): 181-187.

ABSTRACT: The Mussel Watch concept was applied in a study of man-induced chemical changes in the Ebro Delta on the Catalonian coast to obtain a preliminary assessment of the distribution of synthetic organic compounds, petroleum and biogenic hydrocarbons in the local coastal zone. Mussels, oysters and clams were selected as the indicator organisms. Levels of petroleum accumulated by mussels were generally high. The relative distributions of the steranes and pentacyclic triterpanes in the mussels were significantly different from those found in petroleum from a local field, indicating that local petroleum was not contributing to the present contamination. The composition of biogenic compounds was variable, probably reflecting differences in the composition of local plankton communities, PCB levels were high in relation to current levels in mussels from US sites, reflecting continuing PCB use in Spain.

Tavares, T.M.; Rocha, V.C.; Porte, C.; Barcelo, D.; Albaiges, J. 1988. Application of the mussel watch concept in studies of hydrocarbons, PCBs and DDT in the Brazilian Bay of Todos os Santos (Bahia). *Mar. Pollut. Bull.* 19(11): 575-578.

ABSTRACT: Data on aliphatic and aromatic hydrocarbons, PCBs, and DDT in different species of edible bivalves collected along the Todos os Santos Bay (Bahia, Brazil) are reported for the first time for the SW Atlantic coast. The species and collection sites were selected for the identification of suitable regional sentinels and the assessment of different coastal pollutant sources. *Anomalocardia brasiliana*, the dominant and most frequent bivalve of the Brazilian coast, can be an adequate bioindicator because it accumulates organic pollutants with reasonable sensitivity.

Martin, M.; Richardson, B.J. 1991. Long term contaminant biomonitoring. *Mar. Pollut. Bull.* 22(11): 533-537.

ABSTRACT: Heavy metals, halogenated hydrocarbons, and petroleum hydrocarbons in the world's marine and estuarine waters have long been recognized as some of the most potentially deleterious contaminants to biota, and to human consumers of seafoods. During the past two decades, various strategies have been developed to monitor and evaluate the adverse impacts of these compounds in marine waters: one of the most successful efforts has involved the use of bivalve shellfish as sentinel organisms, a technique which has become popularly known as the "Mussel Watch." It is the aim of this article to discuss the need for a more comprehensive contaminant biomonitoring programme in southeastern Australia, with special attention to the marine environment of the State of Victoria.

4.2.2 Parallel Research

Turgeon, Donna D.; Lauenstein, Gunnar G. 1991. Contaminants in mussel tissues from U.S. coastal waters. pp 1842-1858 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Findings are presented from analyses of mollusks collected from sites along the East and West Coasts of the United States, from 1986 through 1989, by the

National Oceanic and Atmospheric Administration's (NOAA's) National Status and Trends Program (NS&T). Contaminant levels in surface sediments and in the tissues of three species of mussels from 96 sites have been used as indicators of the status of coastal environmental quality. Generally, the greatest accumulations of organic contaminants are found in mussel tissues from urban areas. For instance, the highest levels of PAHs were found in samples from the Hudson-Raritan Estuary, NY, and Elliott Bay, WA. The highest levels of PCBs were found at Angelica Rock in Buzzards Bay, MA, followed by moderately high concentrations in the Hudson-Raritan Estuary, NY and NJ, and a second Buzzard's Bay site (Round Hill). Highest levels of DDT were found in mollusks from sites off Palos Verdes and San Pedro Harbor, CA. Uptake of metal contaminants by mollusks is variable among and within genera. Urban sites with high metal and organic contaminant concentrations in mussel tissues are shown to be associated by complete linkage cluster analyses. Comparisons between NS&T data (1986-88) and the Environmental Protection Agency's (EPA) Mussel Watch data (1975-78) indicate significant decadal differences: lead and cadmium in mussel tissues are lower while copper concentrations are higher.

Boudreau, Christine M.; Jenkins, Kenneth D.; Sanders, Brenda M. 1993. Bioaccumulation in mussels caged in Alamitos Bay, California. pp 3355-3370 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Alamitos Bay is a coastal embayment located in the southern portion of the highly urbanized Los Angeles basin. There is concern of the potential for contamination stemming from urban non-point sources and point sources which discharge directly into the Bay and its tributaries. However, current conditions of the Bay are not well documented. To address this problem, we have used caged mussels to ascertain if bioconcentratable trace metals and hydrocarbons were prevalent in Alamitos Bay. We have also used stress proteins to evaluate the potential for sublethal stress. Mussels from a clean source were deployed at various stations in and around the Bay following the Department of Fish and Games' Mussel Sampling Procedures Protocol. After two months of exposure, the mussels were retrieved and analyzed for metal and hydrocarbon content and stress protein concentration. The results indicate a spatial trend of bioaccumulating contaminants. The bioaccumulation data will be compared between stations and with regional data from the California Mussel Watch Program and the National Status and Trends Program. Correlations between bioaccumulation and sublethal stress will also be discussed.

5. Benthos

Many contaminants are adsorbed onto soil particles or other micro-solids in streams and the water column, and eventually collect in estuarine sediments. This often results in a build-up of contaminants to toxic levels. Therefore it is logical that a branch of research would focus on detecting and analyzing the effects of contaminated sediments. It also follows that researchers would look at the impact on organisms that either lie on or burrow through these potentially contaminated sediments, thus adding to the field of potential bioindicators.

5.1 Indicator Organisms

Indicator organisms from the benthos include both benthic (those that live in or burrow through the sediments) and demersal organisms (those that live on the surface of the sediments). Reish (1986) summarizes the efficacy of using benthic invertebrates to determine the degree of past, present, and even the potential for future environmental contamination. Pocklington and Wells (1992) agree with this assessment; however, instead of using benthic invertebrates in general, their review focused the efficacy of using polychaets as bioindicators. In addition these more species specific papers, some authors focused on the more general criteria for choosing an indicator. For example, Pearson et al. (1983) offered a method to detect a species sensitive to pollution induced changes, and Ferraro and Cole (1992) offered an example supporting "taxonomic sufficiency," the idea that species-level indicators are not necessary if the same information can be obtained with less expensive investigations at the higher taxonomic levels.

The next few papers show that while there is wide acceptance of the concept of using benthic organisms as bioindicators, opinions as to which organism should be used vary greatly. For example, Augenfeld (1980) focused on lugworms, Platt and Warwick (1980) favored nematodes, and Breteler et al. (1989) and Thomas (1993) recommend using amphipods. In addition to these studies on benthic invertebrates, there was also some relevant research on demersal organisms, e.g., flatfish. Some of the earlier flatfish research did not always show a strong correlation (Iwaoka et al. 1979), yet later studies (Stein et al. 1992) found them to be quite useful and accurate indicators.

Many of these bioassays have a quantitative basis for determining the level of environmental stress and might therefore be useful indicators for coastal zone managers. This type of indicator also has a public interest component: diseased fish.

5.1.1 Efficacy, Reviews, and Evaluations

Reish, D.J. 1986. Benthic invertebrates as indicators of marine pollution: 35 Years of study. pp. 885-888 in: *Oceans '86 Conference record: Science Engineering Adventure. vol. 3. Monitoring Strategies Symposium*. Marine Technology Soc., Washington; IEEE, New York.

> ABSTRACT: Los Angeles-Long Beach harbors were grossly polluted waters at the time of initiation of benthic invertebrate studies in 1951. Waste discharges included industrial, domestic and storm waters which received little or no treatment. The inner harbor water mass contained little or no dissolved oxygen, but the outer harbor was well oxygenated. Benthic conditions were characterized by four different associations of animals plus an azoic zone. A pollution abatement program was initiated in 1968 and has continued to this day. Waste discharges were either eliminated or diverted to treatment plants. The effects of this abatement program were noted shortly thereafter and had a dramatic effect on the benthic fauna. The azoic and polluted zones were repopulated and are now characterized by a rich, varied benthic fauna. Benthic species known only previously from offshore areas are now resident inhabitants of the outer harbor. The usefulness of benthic monitoring over the past 35 years has demonstrated the rapidity of the improvement of ecological conditions as a result of pollution abatement. Furthermore, the knowledge gained from 35 years of study has provided a valuable data base as future changes in the harbor are contemplated.
> AN: Reish discussed three lessons learned from these 35 years of benthic sampling. First is that **macroinvertebrates** are useful not only in indicating the degree on contamination at the time of sampling, but for past environmental conditions as well. Second, they can serve as indicators of change. Third, since benthic fauna are composed of all the different heterotrophic groups,herbivore, carnivore, detritivorean analysis of the trophic interactions yields a community based technique for monitoring.

Pocklington,-P.; Wells,-P.G. 1992. Polychaetes: Key taxa for marine environmental quality monitoring. *Mar. Pollut. Bull.* 24(12): 593-598.

> ABSTRACT: **Polychaetes** are used: as bioassay organisms, as monitors for toxic materials, and as pollution indicators at the various levels. The literature clearly demonstrates that their use as indicators of marine environmental quality, together with better known methods employing other organisms and assemblages, is widespread on a global scale. It further shows the potential for greater use of polychaetes as biomonitors for compliance and marine environmental quality monitoring purposes, by regulatory and research groups.

Pearson, T.H.; Gray,-J.S.; Johannessen, P.J. 1983. Objective selection of sensitive species indicative of pollution-induced change in benthic communities. *Mar. Ecol. Prog. Ser.* 12(3): 237-255.

> ABSTRACT: An objective technique for identifying potential indicator species using analyses based on the distribution of individuals among species is presented. Benthic

community data from 6 different areas in N.W. Europe are analyzed. In each case species indicative of environmental change in the area are identified, even from areas where such changes are small and have resulted only in minor perturbations in the local community structure. It is shown that particular species groups are characteristically indicative of each area, and that ubiquitous indicator species common to many areas do not occur. The method is rapid and involves little computation; it is robust and can be used across a range of sample sizes; it is theoretically sound and allows the objective selection of species useful as indicators of pollutant effects.

Ferraro,-S.P.; Cole, F.A. 1992. Taxonomic level sufficient for assessing a moderate impact on macrobenthic communities in Puget Sound, Washington, USA. *Can. J. Fish. Aquat. Sci.* 49(6): 1184-1188.

ABSTRACT: Macrobenthic data obtained using three sampling schemes (0.06-m super(2) x 8-cm-deep sampling unit and 1.0- or 0.5-mm-mesh sieves, and 0.1-m super(2) x 8-cm-deep sampling unit and 1.0-mm-mesh sieve) previously identified as optimal or near-optimal for detecting differences between a reference and a moderately impacted station when animals were identified to species were reanalyzed at the genus, family, order, and phylum level to determine the taxonomic level sufficient to detect differences between the stations with t-tests on five measures of community structure. Taxonomically sufficient levels for number of taxa were family in 1.0-mm-mesh samples and species in 0.5-mm-mesh samples. Specific identification was usually required for a Dominance, Shannon's, 1 - Simpson's, and McIntosh's Index in 1.0- and 0.5-mm-mesh samples, suggesting limits to the utility of the taxonomic sufficiency concept when using those indices to detect moderate impacts. This and a previous study indicate that one could reliably (alpha = 0.05, 1 - beta approximately equals 0.80) detect moderate benthic impacts at the study site on number of taxa and five other measures of community structure with five to seven replicate 0.06-m super(2) x 8-cm-deep, 1.0-mm-mesh samples per station and identification to family only. Taxonomic sufficiency can vary depending upon the animal size fraction sampled and the measure used.

5.1.2 Examples

Augenfeld, J. M. 1980. Effects of Prudhoe Bay Crude Oil Contamination on Sediment Working Rates of *Abarenicola pacifica. Marine Environmental Research* 3(4): 307-313.

ABSTRACT: The effect of sediment containing 250, 500, or 1,000 ppm Prudhoe Bay crude oil on the rate of feeding as measured by **fecal production by lugworms** (Abarenicola pacifica) was tested. Both lugworms and sediment were collected from the high intertidal region of an almost-enclosed lagoon adjacent to Sequim Bay, Washington. At oil concentrations of 500 and 1,000 ppm, the rate of feeding was reduced by 70%. **Mean fecal production per unit body weight** was moderately depressed in groups exposed to 250 ppm crude oil. Under normal conditions, smaller animals have higher rates of defecation than larger animals. The test results suggest that defecation rates may have potential application as an indicator of levels of

environmental stress, and that under conditions of moderate pollution, lugworms may aid in recovery of intertidal zones by maintaining sediment transport through feeding activity. (Titus-FRC)

Platt, H.M.; Warwick, R.M. 1980. The significance of free-living nematodes to the littoral ecosystem. pp. 729-760 in: *The shore environment. Volume 2: Ecosystems.* Price, J. H.; Irvine, D.E.G.; Farnham, W.F.-eds.

ABSTRACT: The role played by free-living **marine nematodes** in the littoral ecosystem is assessed. Since little is known of the nematodes of rocky shores, this assessment is based mainly on the results of investigations of particulate shores. Nematodes are considered to be the most ubiquitous, abundant and diverse marine metazoan group. They are of major energetic importance, form a significant part of the diet of many other animals, play vital roles in facilitating decomposition and in influencing the physical stability of beaches, and are potentially important indicators of environmental conditions. The authors conclude that any general assessment of intertidal habitats is incomplete if the nematode fauna is not taken into consideration.

Breteler, R.J.; Scott, K.J.; Shepherd, S.P. 1989. Application of a new sediment toxicity test using the marine amphipod *Ampelisca abdita* to San Francisco Bay sediments. *Aquatic toxicology and hazard assessment* 12: 304-314. Cowgill,-U.M.;Williams,-L.R.-eds.

ABSTRACT: Sediment bioassays are becoming widely recognized as effective tools to determine the biological significance of the contamination found in coastal sediments. This paper describes the application of a new sediment toxicity test with Ampelisca abdita , a **marine amphipod**, to sediments from three stations at each of four sites in San Francisco Bay and one reference site in Tomales Bay. Results indicated that the range of mortality within each station was generally less than 10%. Statistical analyses indicated highly significant site differences for both mortality and emergence. San Pablo Bay and Tomales Bay sediments were, as expected, the least toxic, with mean ten-day mortalities of 8.7 and 11.0%, respectively. Yerba Buena and Vallejo sediments were slightly, but significantly, more toxic at 15.0 and 14.7%, respectively; and the Oakland Harbor sediments were the most toxic, with 25.7% mortality.

Thomas, J.D. 1993. Biological monitoring and tropical biodiversity in marine environments: A critique with recommendations, and comments on the use of amphipods as bioindicators. *J. Nat. Hist.* 27(4): 795-806.

ABSTRACT: Preoccupations with regulatory and legal liability issues in marine environmental monitoring have led to programmes based on reductionist models that use nonbiological parameters which are indirect measures of biotic condition. The ability to assess the effectiveness of current monitoring programmes to protect the marine environment at regional and national scales does not currently exist. Current monitoring programs rarely serve the function for which they were intended: an accurate and sensitive source of information from which conditions and trends can be defined and recognized, and management decisions made. In addition, the natural

variability of systems is problematic and must be documented in order to distinguish natural from anthropogenic changes in environmental conditions. Owing to their ecological importance, numerical abundance, and sensitivity to a variety of toxicants and pollutants, **amphipod crustaceans** have long been known as sensitive environmental indicators. However, application and use of amphipods in such programs is limited to the few regions where ongoing comprehensive taxonomic and natural history investigations have been undertaken. Potential for amphipods as bioindicators exists in a wide variety of environments, especially in the tropics, but their incorporation into such programs is dependent upon completion of taxonomic surveys and inventories.

Iwaoka, W.T.; Landolt, M.L.; Pierson, K.B.; Felton, S.P.; Abolins, A. 1979. Studies on aryl hydrocarbon hydroxylase, polycyclic hydrocarbon content, and epidermal tumors of flatfish. pp. 85-93 in: *Animals as monitors of environmental pollutants. Symposiun on pathobiology of environmental pollutants: animal models and wildlife as monitors.*

ABSTRACT: A preliminary survey on histopathology, **liver aromatic hydrocarbon content, and aryl hydrocarbon hydroxylase levels of flatfish** from several selected sites in Puget Sound and Canadian waters was made to determine how well the flatfish qualifies as a wildlife monitor of pollution. No significant correlations were found, although certain GLC and other data indicate that further study is needed.

Stein, J.E.; Collier, T.K.; Reichert, W.L.; Casillas, E.; Hom, T.; Varanasi, U. 1992. Bioindicators of contaminant exposure and sublethal effects: Studies with benthic fish in Puget Sound, Washington. *Environ. Toxicol. Chem.* 11(5): 701-714.

ABSTRACT: A suite of chemical and biochemical variables responsive to contaminant exposure was measured in three species of **benthic flatfish** (English sole, *Parophrys vetulus*; rock sole, *Lepidopsetta bilineata*; and starry flounder, *Platichthys stellatus*) sampled from up to five sites in Puget Sound, Washington, to assess the sensitivity of the parameters to differences in levels of contaminant exposure. The results showed (a) that all the examined indexes could discriminate among sites exhibiting different degrees of chemical contamination, (b) that species differed in the range of response of most of the measured indexes, and (c) that the use of the indexes in concert appeared to enhance the assessment of contaminant exposure and sublethal effects.

ANNOTATION: This was one of the few studies that coupled biochemical measurements and physiological indexes with chemical analyses in assessing the level of exposure of fish to chemical contamination. One benefit of this it that it allows enhances assessment of the impact of contaminants on exposed species.

5.2 Research Trends

Early benthic research first focused on chemical analyses of the sediments to determine the amount or concentration of metals, hydrocarbons, etc. in the sediments. Standard methods for chemical analyses have long been established; recent papers focus on minor improvements. Readman et al. (1986) focused on ways to help make water quality sampling and testing more efficient, and Stone et al. (1993) improved upon earlier sediment core research by increasing the core depths from several feet to 15 to 20 feet, allowing a direct comparison between the upper polluted sediments and lower clean sediments. However, most of the research focused on bioindicators.

Bioindicator research tended to follow one of three different pathways. In the first pathway, researchers looked at the environmental effects of pollutants on the benthic community (Read et al. 1983 and Sandulli and De-Nicola-Giudici 1989). This type of research is also exemplified by the National Status and Trends program's Benthic Surveillance Project. This is similar to the National Status and Trend's Mussel Watch program but it looks at bottom-dwelling fish and associated sediments rather than bivalves. Other differences are that it studies less than half the number of sites, and that it was a much less popular research subject. One of the few papers mentioning this project was Wolfe et al. (1993) who reviews bioeffect surveys. This type of research is an important part of determining whether an organism is suitable as an indicator, but has no direct effect for this project.

The second pathway is more useful in that compares existing indicators or identifies potential new bioindicators. On the comparison side, Raffaelli (1982) compares six major mieofaunal groups and Satsmadjis (1985) compared phytoplankton and macrozoobenthic organisms. The "new" bioindicator research, although they have not gone through years of peer reviewed scrutiny might nonetheless be useful as an environmental indicator. Collier et al. (1989) identified an "early exposure" indicator of sediment contamination. This could be a major improvement because most other indicators have a substantial temporal lag. Gastropod imposex (imposition of male sexual characteristics on female marine snails) is also useful because it offers an effective and inexpensive indicator of tributyltin contamination (Ellis and Pattisina 1990, and Foale 1993). As discussed in the previous section, this type of research is the most useful for developing useful indicators of environmental quality.

The third pathway critiques the efficacy of bioindicators and in some cases, offer an alternative to improve the perceived shortcomings in the bioindicator model. Tietjen (1977) concludes that nematodes are not useful bioindicators for either metal or organic carbon deposits. Platt et al. (1984) find the models of a keystone species and multi-species indices (i.e. diversity indices and the nematode-copepod ratio) unfeasible, unreliable or impractical. In a contrasting view, Shiells and Anderson (1985) support the nematode/copepod ratio and provide a practical application of its use. The abundance/biomass comparison method gave us another quantitative measure for detecting pollution effects (Meire and Dereu 1990). These newer models may provide a better quantitative measure, but they are not as widely accepted as the simpler bioindicator and they may be harder for the public to understand.

5.2.1 Direct Measurements

Readman, J.W.; Preston, M.R.; Mantoura, R.F.C. 1986. An integrated technique to quantify sewage, oil and PAH pollution in estuarine and coastal environments. *Marine Pollution Bulletin* 17(7): 298-308.

> ABSTRACT: An analytical protocol is described which allows parallel quantification of sewage, oil and PAH pollution on the same sample, thus maximizing the information gained for the effort expended. Capillary gas chromatography-flame ionization detection (GC-FID), now a routine technique in many laboratories, has been selected as the method for quantification. The protocol described is evaluated, and analyses of sediments from estuaries of the Rivers Mersey, Dee and Tamar, UK, are given as examples of how to interpret results achieved using the technique.

Stone, Gregory W.; Watson, J.S.; Walker, J.T.; Morgan, J.P. 1993. Heavy metal accumulation in subsurface, estuarine sediments and inferences for anthropogenic enrichment: N.W. Florida coast. pp 899-914 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: In an attempt to quantify the degree of contamination and the thickness of the contaminated subsurface sedimentary wedge, approximately 100 samples were extracted from the cores and subjected to grain-size and heavy metal (Al, Fe, Cd, Cr, Cu, Co, Pb, Mn, Ni, Zn) analyses. Detailed lithofacies descriptions in addition to the composition and texture of sediments in the cores permitted identification of Plio-Pleistocene and Holocene boundaries. Metal concentrations found in theses sediments were used as "background" trace metal levels in "natural" (uncontaminated) material where the subsurface remained undisturbed by human activity (dredging in, spoil deposition, etc.) Anthropogenically-induced, metal enrichment was clearly evident in the bayou, although the thickness of the contaminated wedge varied due to sedimentation rates, flushing capacity, local geology of the watershed and the degree of industrialization or urbanization. The principal advantage of this approach over other (e.g. normalization), is that the "clean" Holocene sediment, which is primarily homogeneous, monomineralic (quartz sand) material, can be readily sampled progressively upcore resulting in the precise location of the contaminated sedimentary wedge. (Edited author abstract) Refs.

5.2.2 Effects on the Organism

Read, P.A.; Anderson, K.J.; Matthews, J.E.; Watson, P.G.; Halliday, M.C.; Shiells, G.M. 1983. Effects of pollution on the benthos of the Firth of Forth. *Marine Pollution Bulletin* 14(1): 12-16.

> ABSTRACT: A long-term benthic study has been undertaken in the Firth of Forth to assess the environmental impact of a new sewage treatment scheme for the city of Edinburgh. The sewage scheme reduced the suspended solids content of the liquid effluent by approximately 60% and achieves a lowering of the concentration of

materials in solution through more efficient dilution and dispersion. Marked changes in the intertidal benthic flora and fauna have been recorded along the Edinburgh coastal zone. These changes have apparent as the decline and disappearance of populations of certain **pollution indicator species** and the appearance and establishment of several species previously unrecorded along the more polluted parts of the Edinburgh shoreline.

Sandulli, R.; De-Nicola-Giudici, M. 1989. Effects of Organic Enrichment on Meiofauna: A Laboratory Study. *Marine Pollution Bulletin* 20(5): 223-227.

ABSTRACT: An experiment was conducted to examine the effects of different loadings of organic enrichment on meiobenthos and, in particular, on its most abundant components, **nematodes and harpacticoid copepods**, to assess their potential as environmental quality indicators. An 84 day laboratory experiment indicates the decline of intertidal meiofauna abundance may be directly related to treatment level and time of exposure to sewage sludges. The observed changes revealed a marked decrease of nematodes and total disappearance of mesobenthic harpacticoids while the non-interstitial copepod species were little affected. Results support the use of the nematode/copepod ratio as an index of organic pollution, and its used could be enhanced by considering in the calculation only truly interstitial species, apparently the most sensitive to environmental stress, since differences in the habitat requirements of nematodes and copepods may be essential to determine their response to organic enrichment.

Wolfe, D.A.; Long, E.R.; Roberston, A. 1993. NS&T intensive bioeffects surveys: design strategies and preliminary results. pp 298-312 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Intensive bioeffects surveys are conducted in selected areas where chemical data from the National Status and Trends (NS&T) Program indicate greatest potential for contaminant-related biological effects. The surveys examine biomarkers of contaminant effects in resident fish and mollusks to determine the occurrence and magnitude of bioeffects in the natural system. **Sediment toxicity surveys** provide finer resolution on the spatial distribution of potential contaminants effects than is possible from the responses in mobile feral organisms. Surveys have been conducted in San Francisco Bay, Hudson-Raritan Estuary, Tampa Bay Boston Harbor, and Long Island Sound. Within these regions, fish from areas with the greatest contaminant loadings frequently exhibit higher incidences of contaminant-related histopathologies, along with elevated incidences of DNA adducts. Sediment toxicity is usually estimated using three or more exposure modes and test endpoints to support intercomparison of test sensitivities and correlations with contaminant concentrations. Sediment toxicity, occurs in portions of all study areas to date, being generally higher in sediments collected near urban or industrial centers and diminishing away from those centers. This paper outlines the rationale and design for the surveys, and presents representative results for Tampa Bay.

5.2.3 Comparing or Identifying Bioindicators

Raffaelli, D. 1982. An assessment of the potential of major meiofauna groups for monitoring organic pollution. *Mar. Environ. Res.* 7(2): 151-164.

> ABSTRACT: The numbers of six meiofauna groups (**nematodes, copepods, turbellarians, archiannelids, oligochaetes and gastrotrichs**) were estimated from 17 sandy beaches differing in their organic (sewage) pollution loadings. Nematodes were most abundant on polluted and fine sand beaches whilst copepods were more common on coarse sand and rare on polluted beaches. The **ratio of nematodes to copepods may thus provide a useful index of beach quality**. Archiannelids and oligochaetes seem restricted to particular habitat types and, with the turbellarians, have little potential for biomonitoring. Gastrotrichs occurred in large numbers on one polluted beach.

Satsmadjis, J. 1985. Comparison of Indicators of Pollution in the Mediterranean. *Marine Pollution Bulletin* 16(10): 395-400.

> ABSTRACT: An attempt is made to evaluate different ways of estimating the extent of pollution in coastal areas, using data relating to Greece. The investigation reveals basic faults in the procedures. The concentrations of dissolved in organic nutrients do not necessarily reflect the amounts of domestic wastes discharged into the location. The levels in the sea or marine organisms of impurities from industrial effluents may alter greatly in the same region from one date or spot to another. The metal content of unsullied sediments depends on its granulometric composition. Phytoplankton density varies according to, not only the availability of nutrients, but also the season and the rate of grazing. On the contrary, **macrozoobenthos**, being much less influenced by transient changes in the environment, affords a reliable picture of its average state. This fact enables the development of a method for the assessment of the degree of pollution on the basis of the diversity and abundance of the biocenoses, as well as other factors.

Collier, T.K.; Eberhart, B. T.L.; Stein, J.E.; Varanasi, U. 1989. Aryl hydrocarbon hydroxylase—a "new" monitoring tool in the Status Trends Program. pp. 608-610 in: *Oceans '89: The Global Ocean. Volume 2: Ocean Pollution.*

> ABSTRACT: To better assess the effects of contaminant exposure on animals, it is desirable to identify and measure effects of contaminant exposure which occur relatively early after exposure and which occur in most, if not all, species of interest. Certain biochemical effects, such as increases in activities of mixed function oxidase (MFO) enzymes, fulfill these two conditions. The authors have been evaluating the use of the MFO system as an early effects measurement for the NBSP, specifically, measuring hepatic **aryl hydrocarbon hydroxylase (AHH)** activity towards a common anthropogenic contaminant, benzo(a)pyrene (BaP). Overall, results have shown that measurement of hepatic AHH activity is a highly responsive indicator of contaminant exposure in benthic fish, making this measure an effective tool for use in environmental monitoring programs.

Ellis, D.V.; Pattisina, L.A. 1990. Widespread neogastropod imposex: A biological indicator of global TBT contamination? *Mar. Pollut. Bull.* 21(5): 248-253.

> ABSTRACT: **Imposex** (male genitalia imposed on females) in shoreline whelks and other neogastropod molluscs is reported here from S.E. Asia (Singapore, Malaysia and Indonesia). In Singapore, imposex occurred at all sites where females were available. In remote Ambon Bay, Indonesia, imposex also occurred widely, and was particularly severe in two harbours for high seas and inter-island vessels. We conclude that it is now global, not just regionally localized. From the association of neogastropod imposex with tributyltin (TBT) contamination derived from boat and ship anti-fouling paints, it follows that TBT contamination and its human consequences should be considered a contemporary global threat. We present here an imposex survey protocol for neogastropod species in general.

Foale, S. 1993. An evaluation of the potential of gastropod imposex as a bioindicator of tributyltin pollution in Port Phillip Bay, Victoria. *Mar. Pollut. Bull.* 26(10): 546-552.

> ABSTRACT: Imposex, the imposition of male sexual characteristics on female marine snails, was used as an indicator of past and present exposure to tributyltin (TBT) in the abundant muricid whelk *Thais orbita* (Gmelin). Wild populations of *Thais orbita* were surveyed for frequency and intensity of imposex throughout Port Phillip Bay and at two sites on the adjacent oceanic coast. Imposex indices correlated strongly with proximity to marinas or harbours. Average TBT body burdens for each population were mostly below 10 ng/g Sn (as TBT, wet wt) and failed to correlate with imposex indices. Even the highest body burdens were indicative of low contemporary ambient TBT levels. *Thais orbita* females from a population with negligible levels of imposex were transplanted to two sites where the highest imposex indices were found. Transplants failed to develop a significantly higher frequency or intensity of imposex than controls after 11 weeks. These results confirm that, as with many other gastropod species, imposex in *T. orbita* is irreversible, and may be found in populations where TBT contamination is no longer present. Nevertheless, controlled transplantation of *T. orbita* shows promise as a routine bioindicator of contemporary TBT contamination in southern Australia. Imposex in other gastropod species in Port Phillip Bay is described and discussed.

5.2.4 Critiques and Improvements

Tietjen, J.H. 1977. Population distribution and structure of the free-living nematodes of Long Island Sound. *Mar. Biol.* 43(2): 123-136.

> ABSTRACT: The distribution and structure of nematode populations in 4 sedimentary environments (muds, muddy sands, fine sands and medium-coarse sands) in Long Island Sound were studied. Mean population densities were highest in muds and muddy sands. Cluster analysis suggested the presence of two basic faunistic units; a mud unit characterized by high species dominance, low species diversity and low species endemism, and a sand unit characterized by low species dominance, high

species diversity and high species endemism. Species diversity in all habitats was a direct function of both species richness and equitability. Limited niche separation among deposit feeders, usually the dominant nematode trophic type in muddy sediments, is proposed as the cause for the high species dominance so often characteristic of shallow marine muds. The study afforded the opportunity to examine the quantitative and qualitative aspects of population structure in relation to environmental impact (as indicated by large differences in the heavy metal and organic carbon concentrations within each of the 4 sedimentary regimes). Within each sediment type no differences in population densities, species composition or species diversity of nematodes existed between heavily impacted and apparently non-impacted sediments, or between Long Island Sound and similar coastal regions. These findings cast doubt on (1) the use of heavy metal and organic carbon concentrations as indicators of environmental stress for marine nematodes; (2) the use of diversity indices alone as indicators of environmental deterioration; and (3) the usefulness of field monitoring studies alone for the assessment of pollution impact on **marine nematodes.**

Platt, H.M.; Shaw, K.M.; Lambshead, P.J.D. 1984. Nematode species abundance patterns and their use in the detection of environmental perturbations. *Biology of Meiofauna* (C. Heip, ed.) 118(1): 59-66.

ABSTRACT: If the concepts of biological indices and biomonitoring at the multi-species level are to prove viable, then meiofauna and marine nematodes in particular should be an ideal group with which to test the hypothesis. Many attempts to assess the structure of species assemblages, such as the use of diversity indices, nematode: copepod ratio and the graphical method of log normal plots, have been shown to be theoretically unsound and/or impractical, especially for routine use by extension workers. A method of assessing shifts in dominance patterns which involves all the proportional species abundances is suggested as a better means of comparing diversity. A modified method of rapidly assessing **Simpson's dominance-weighted diversity index** is also advocated as being of practical use. In combination, they should enable the diversity aspect of the multi-species approach to biomonitoring to be rigorously and exhaustively evaluated.

Shiells, G.M.; Anderson, K.J. 1985. Pollution monitoring using the nematode/copepod ratio. A practical application. *Mar. Pollut. Bull.* 16(2): 62-68.

ABSTRACT: The practical application of the **nematode/copepod ratio** in a pollution monitoring study in the Firth of Forth was investigated. Ratios from polluted sites were much higher than from a clean site, but there is considerable evidence which casts doubt on the credibility of the ratio as a tool to detect organic pollution. Nematodes and copepods exhibited differing degrees of contagion. Seasonal patterns of variation of the ratio were shown to vary geographically and at some sites the seasonal range was great. Along sewage pollution gradients in time and space the ratio was shown to vary in an inconsistent manner. A possible improvement to the ratio whereby only interstitial forms are included is suggested.

Meire, P.M.; Dereu, J. 1990. Use of the abundance/biomass comparison method for detecting environmental stress: Some considerations based on intertidal macrozoobenthos and bird communities. *J. Appl. Ecol.* 27(1): 210-223.

ABSTRACT: The **abundance/biomass comparison (ABC)** method for detecting pollution effects was applied to data for macrozoobenthos taken from two intertidal areas: one virtually unpolluted (the Oosterschelde, Netherlands in 1981-84) and the other very polluted (the Westerschelde, Belgium in 1987). Studies of **macrozoobenthos** from several study plots in the Oosterschelde indicated some environmental stress, related to a long tidal exposure time of the plot or to human disturbance (mussel fishing). In the Westerschelde, the ABC method indicated an unstressed (unpolluted) situation in one and a moderately stressed (polluted) situation in two study plots. Applying the method to data for waders taken from the same study plots in the Oosterschelde revealed stress only in the plots with the shortest exposure time and the lowest available invertebrate biomass. It is argued that it is difficult to use this method in estuarine areas as an indicator of pollution because of the environmental stress typical for these areas. However, in general, it may be used to detect environmental stress.

6.0 Indicators from the Coastal Zone Management Literature

The papers cited are grouped into the following headings: Coastal Zone Management Reviews, Buffer Zones, Public Access, Coastal Hazards, and Marine Debris. Suggestions on how to make research more useful to developing indicators are also discussed in each group.

6.1 Coastal Zone Management Reviews

A number of articles attempt to evaluate the Coastal Zone Management Act as well as specific state coastal zone management programs. However, these articles were generally limited to programmatic descriptions or critiques, and to prescribing concepts such as better agency cooperation and more effective regulations. A few mentioned concepts that could lead to the development of indicators (Englander 1977, Archer 1985 and Wilson 1985), but for the most part, these types of papers addressed program assessment such as the consistency of state CZM programs with national goals. There appears to have been little growth in developing quantitative indicators. Many of the same problems and needs addressed in Englander (1977) were reiterated eight years later by Wilson (1985).

Although these reviews have correctly highlighted the need for measurable evaluative criteria, very few exist. Moreover, existing measurable criteria only have limited utility. For example, the two best CZM evaluations found in this literature search were simple site specific evaluations using water and sediment quality data (Paulson 1989 and Guillen 1993). A less quantitative but still potentially useful approach is offered by (Born and Miller 1988). Here they assess CZM programs by asking specific evaluative questions.

Englander, Ernie, Jim Feldman, and Mark Hershman. 1977. Coastal zone problems: a basis for evaluation. *Coastal Zone Management Journal* 3(3): 217-235.

> ABSTRACT: An important but difficult step in evaluating coastal programs is the formulation of meaningful and measurable criteria for purposes of evaluation. One useful source for deriving evaluation criteria consists of coastal problem statements. This article summarizes perceived coastal zone problems identified prior to the passage of the 1972 Coastal Zone Management Act and discusses how this information could be used in formulating criteria for evaluating coastal problems.
> AN: The authors divided problems into two distinct groups: (1) Resource outcome problems are dissatisfactions with the state of the natural resource; (2) Organizational process problems are the characteristics or procedures that inhibit an organization from attaining its goals and objectives. The predominant resource outcome problems were (i) intense-use conflicts among competing uses, (ii) extensive environmental pollution, (iii) and destruction of coastal habitat and degradation of fish and wildlife resources. The predominant organizational process problems were (i) lack of coordination among public agencies, (ii) insufficient planning authority, (iii) insufficient data

base and lack of information for decision making, (iv) little understanding or knowledge about coastal ecosystems, and (v) resource decisions made primarily on the basis of economic considerations to the exclusion of ecological considerations.

Archer, J.H. 1985. The concept of coastal zone management. *Proceedings of the Int. Symposium on Utilization of Coastal Ecosystems: Planning, Pollution, and Productivity.* (Labish-Chao, N.; Kirby-Smith, W. eds.) 1: 27-38.

ABSTRACT: Competing pressures on the coastline of the United States led to the passage of the Coastal Zone Management Act of 1972. The act recognized the roles of local, state and federal government by establishing a partnership process for managing coastal resources. The federal role was designed to provide a degree of continuity and to assure that all states receiving federal financial assistance were complying with the basic objectives established in the Act. After ten years of experience, federal financial assistance is phasing down. The future success of the state coastal zone management programs will depend in great part on the degree of achievement realized to date. Achievements have been made in the following areas: (1) permit simplification and streamlining; (2) development of ports and waterfronts; (3) prevention of loss of life and property due to improper development in coastal hazard areas; and (4) protecting natural resources.

Wilson, Katharine A. 1985. Improved evaluation of the federal CZM program. *Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: The Coastal Zone Management Act (CZMA) of 1972 created a federal coastal zone management program by providing funds to states to voluntarily develop and implement plans for the management and protection of their coastal resources. This approach, unique among natural resource laws, makes the outcome of the CZMA's implementation of particular interest to policy-makers. this paper reviews past evaluations of the Federal Coastal Zone Program and outlines the obstacles which have thwarted more meaningful and objective evaluation of this program. It further reviews a case study national program evaluation which utilizes explicit, relatively objective evaluative criteria and illustrates some of the barriers encountered in conducting national program evaluation. Recommendations derived from the literature review and case study for improving future evaluation of the federal coastal zone management program are presented.

Paulson, Anthony J.; Hubbard, Thomas P.; Curl, Herbert C Jr.; Feely, Richard A.; Sample, Timothy E.; Swartz, Robert G. 1989. Decreased fluxes of Pb, Cu and Zn from Elliott bay. pp 3916-3930 in: *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Fluxes of dissolved Pb, Cu and Zn to Elliott Bay, Washington from industrial sources were calculated from metal-salinity plots and freshwater discharge rates. The changes in these calculated fluxes were used to evaluate the effectiveness

of pollution abatement programs. Between 1981 and 1985, initial pollution abatement actions were directed at many commercial and industrial dischargers along the Duwamish Waterway and on Harbor Island including a secondary lead smelter site and shipbuilding facilities. Subsequently, the dissolved Pb flux to Elliott Bay from industrial sources decreased by a hundred-fold, the industrial flux of dissolved Cu decreased by a factor of 5, and the industrial flux of dissolved Zn remained unchanged. The closure of one shipyard, reduced activity at another and **better management practices decreased the industrial fluxes of dissolved Cu and Zn to Elliott Bay** in 1986 by 75% and 90%, respectively. (Author abstract) 20 Refs.

Guillen, George. 1993. Evaluation of dissolved oxygen and nutrient trends in the Houston ship channel from historical statewide monitoring data. pp 518-527 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Dissolved oxygen and selected nutrient trends in the Houston Ship Channels (Texas Water Commission (TWC) segments 1007, 1006 and 1005) during the period of 1969 through 1990 were evaluated using non-parametric time series analysis. Surface and/or bottom concentrations of dissolved oxygen, ammonia nitrogen, nitrate nitrogen, orthophosphate, and total phosphorus from selected stations were evaluated. These data indicate that dissolved oxygen levels have increased in the Houston Ship Channel over the last 20 years when adjusted for seasonal variation. During this period of time point source wastewater loading (lb/d BOD) from domestic and industrial sources has decreased. Resulting decreases in phosphorus compounds and ammonia nitrogen, and increases in nitrates as a result of enhanced nitrification, have also occurred. Increased aquatic life use in the HSC has been documented by other TWC studies as a result of these increasing trends of dissolved oxygen. It is highly probable that the **increased dissolved oxygen levels** observed in the HSC are due to increased regulation and enforcement by state and federal agencies, increased facility compliance, and subsequent decreases in wastewater effluent loading and bypasses. These results illustrate the importance and application of a well designed monitoring program for the purposes of tracking the effectiveness of water quality management. (Author abstract)

Born, S.M.; Miller, A.H. 1988. Assessing networked coastal zone management programs. *Coastal Management* 16(3): 229-243.

ABSTRACT: During the early development of the national coastal zone management program there was no federal prescription with regard to how coastal states should proceed in establishing their programs institutionally. An approach that relied on existing agencies and authorities and improved policy development and coordination; was described as "networking." Many coastal advocacy groups, academics, and bureaucrats viewed the networked model with skepticism. With more than a decade of experience, the authors review and critique the efficacy of this approach to coastal management. Lessons learned from experimentation with networked coastal manage-

ment programs may provide important lessons for other regional land and water resources management efforts.

ANNOTATION: The paper poses three questions that would aid in the evaluation of CZM programs: [1] Did the coastal program precipitate institutional change? (policy, organization, budget and or process); [2] Did the coastal program precipitate changes inland and water uses? (patterns of use and or resource protection); and [3] Did the coastal program satisfy its constituents?

6.2 Buffer Zones

Buffer zones include buffer zones for construction setbacks, wetlands, and water quality. Presently, the most useful indicator concerns construction setbacks. For example, Stutts (1985) was able to measure a building owner's degree of safety by comparing the building's landward distance to the estimated erosion rate. Other work confirms the need for site specific geologic testing (McCarthy and Tobin, 1985) and reviews and highlights the desirable features of individual state setback programs, noting in one of three desirable features that setback programs need to understandable to the public (Houlahan, 1989).

Work on habitat and water quality buffer zones have also had detailed research. For example, Diamond (1988) offers a method for determining wetland buffer width that takes into account a variety of factors, and Phillips (1989) evaluates the factors determining the effectiveness of water quality buffer zones to determine the relative influence of soil properties, geomorphology, and surface conditions.

Buffer zones could be a useful indicator of environmental quality in that if they are properly followed, they can ameliorate potential anthropogenic affects, but what is the useful measurement? While the buffer zone research presented in this literature review is important, it is more process rather than outcome oriented and therefore is not as useful when trying to develop measurable indicators of environmental quality.[4]

Stutts, Alan T., Chrystos D. Siderelis, and Spencer M. Rogers, Jr. 1985. Effect of ocean setback standards on the location of permanent structures. p 2459 in: *Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: A measure of the degree of safety from long-term erosion can be estimated by comparing the actual distance an owner chooses to locate landward of the required setback with the estimated erosion rate. This analysis describes where

[4] The use of buffer zones as an indicator of coastal zone quality is problematic. The basic goal of both the federal Coastal Zone Management Act and Washington's Shoreline Management Act is to foster appropriate development and human activities in the coastal zone. Buffers have a role to play under specific circumstances.

permanent structures were located in relation to the setback requirements during 1979-1981. The study concludes that as expected the ocean setback line undoubtedly required some buildings to be sited farther from the ocean than would have been the case without the regulation. However, an undesirable effect of the setback regulation is to encourage an owner to locate at the minimum required distance even when safer, more landward locations are available on the lot.

McCarthy, Richard J. and L. Thomas Tobin. 1985. Blufftop Setbacks-A Regulatory Impossibility? p 1600 in: *Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: The California Coastal Act requires that new development must minimize risks to life and property, assure geologic stability and structural integrity, not contribute significantly to erosion, or require the construction of a protective device during the design life of the structure. This regulatory concept is innovative but highly controversial and difficult to enforce with consistency. Coastal blufftop erosion rates vary greatly along California's 1075 miles of coastline. Therefore, a uniform state-wide coastal blufftop setback distance is impractical, especially when the decision to grant a development permit may be based solely on whether or not the structure will require a coastal protective device at any time during its proposed design life. Because of this, the California Coastal Commission requires a geotechnical study be done for any structure located within the "area of demonstration," the description of which is set forth in the "Statewide Interpretive Guidelines."

Houlahan, J.M. 1989. Comparison of state construction setbacks to manage development in coastal hazard areas. *Coastal Management* 17(3): 219-228.

ABSTRACT: The different types of state setback programs enacted to protect property and lives from coastal erosion hazards are described. Eleven states currently use construction setbacks. Annual long-term average recession rates are the basis for the majority of state setbacks. Existing state setback programs are compared and their strengths and weaknesses discussed. Three desirable features of existing state setback programs are examined: (1) designate "low" and "high" hazard areas, (2) consider structure size in determining the setback distance, and (3) make the setback program understandable to the public.

Diamond, R.S.; Nilson, D.J. 1988. Buffer delineation method for coastal wetlands in New Jersey. pp. 771-784 in: *Proceedings of the Symposium on Coastal Water Resources* (Lyke, W.L.; Hoban, T.J. eds.).

ABSTRACT: The buffer delineation method described in this paper has been developed for the New Jersey Department of Environmental Protection, to be used to determine appropriate buffer widths for both tidal and non-tidal wetlands. The method addresses potential impacts that results from land was of varying intensity, and the water quality renovation capability of buffers. Water quality renovation capability was determined based on a combined evaluation of buffer slope, vegetation, and soil

characteristics. Impacts of residential, commercial, and industrial development were studied at low, moderate, and high intensities (based on percent impervious surface).

Phillips, J.D. 1989. An evaluation of the factors determining the effectiveness of water quality buffer zones. *Journal of Hydrology* 107(1-4): 133-145.

ABSTRACT: This study examines the relative role of slope length, slope gradient, surface roughness, and soil hydrologic properties in determining the pollution control effectiveness of vegetated buffer zones. Two models describing buffer conveyance capacity are introduced. The hydraulic and detention models, respectively, are applied to the problem of estuarine shoreline buffer zone delineation in Carteret County, North Carolina. Results show that where solid-phase pollutants transported as suspended or bedload in overland flow are the major concern, slope gradient is the most critical factor, followed by soil hydraulic conductivity. Where dissolved pollutants that are transported by both surface and subsurface flow are of concern, buffer width is by far the most important factor, with soil moisture storage capacity also playing a role. Methods developed here may be applied to any water quality buffer delineation problem to determine the relative influence of soil properties, geomorphology, and surface conditions.

6.3 Public Access

Public access is a well researched topic in the coastal zone management literature. However, most of the work evaluates or describes the legal basis for public access and is not directly applicable the development of coastal quality indicators.

Scott (1987), however, discusses Washington state's 'supply' of public access in terms of sites on a per capita basis, and site usage—two quantitative measures of public access. Kominsky (1985) and Wakeman (1991) describe programs to improve public access but only in terms of a net increase. While there may have been a net increase in the number of access points, there is no measure of the per capita effect. Because many coastal populations are increasing, the number of public access sties per capita could be decreasing.

Scott, James W. 1987. Washington state public access program: Finding solutions to the shortcomings. pp 4338-4343 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal & Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: This paper discusses the problems of providing adequate public access and focuses on many of the solutions which have been found and implemented in Washington State. In 1983, the Shorelands program of the Department of Ecology evaluated 12 years experience under State Shoreline and Federal Coastal Zone management. It was determined that despite legislative priorities shoreline public access had only modestly increased. Almost all the measurable increases were from outright acquisition and development of sites by public agencies, not from condition-

ing shoreline development permits. As a result of the evaluation study, the Department of Ecology placed emphasis on public access. (Edited author abstract)
AN: The author describes two deficiencies in public access to the shoreline. One is that there is an inadequate number of sites to meet demand and that the sites are unevenly distributed. The second is that the public in many instances does not know about and can not find many existing public access sites.

Kominsky, Karen J. 1985. Improving public access to the New Jersey shoreline. p 1729 in: Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management. American Society of Civil Engineers, New York.

ABSTRACT: The New Jersey Coast is a magnificent natural resource. Its 126 miles of ocean beaches provide enjoyable recreational opportunities for residents of and visitors to the state. The state's second largest industry, tourism, is dependent on the use of coastal beaches. In 1982, tourism in the Atlantic coastal area produced $4.9 billion in revenues in addition to having generated a large number of jobs. (DEP, 1983). However, not all beaches are open to the public. The New Jersey shoreline is characterized by differing degrees of development and ownership. These differing conditions create a major issue for those who live, work and visit the coast: the availability of public access. This issue has become increasingly important in the past three decades as highway construction, improved transportation and increased affluence have made it easier for people to go to the beaches. Also, undeveloped oceanfront land has become increasingly scarce, elevating coastal land values.

Wakeman, N. 1991. Providing access for the public to the shoreline of San Francisco Bay. *Marine Pollution Bulletin* 23: 637-638.

ABSTRACT: This paper will discuss how the San Francisco Bay Conservation and Development Commission has responded to the public need to get to the shoreline and view the water as part of its regulatory program for the San Francisco Bay Area. The Commission's authority will be discussed as well as the way the Commission uses its Design Review Board and design guidelines to assure that public access areas are well designed and integrated into project development.

6.4 Coastal Hazards

Coastal hazards includes coastal flooding, coastal erosion, and sea level rise. The papers on flooding and sea level rise were solely descriptive or programmatic, and therefore were not useful to this project. The erosion literature too is largely descriptive. Terich and Gabriel (1987) report that long term erosion on the Washington coast had no apparent effect on land sale values. Ives and Furuseth (1988) found that residents of the North Carolina coast regarded erosion as a natural process and a risk to be accepted. Kucma-Kenney and Nordstrom (1985) report that while coastal erosion is a serious problem on most of the United States coast, the public is disinterested unless they are directly affected. Griggs (1987)

reports that about 86 percent of California's coast is eroding and that ten percent has been armored.

Erosion is a natural process. It becomes a problem when it affects the value or use of property. When the problem becomes noticeable to the property owner, a common response is to construct a concrete bulkhead or rock wall, which has its own negative effects on coastal zone quality (Shipman and Canning, 1993).

Shoreline armoring as a response to erosion has the potential of being an indicator, but the literature is still too descriptive. To be a useful indicator of shoreline quality, researchers need to develop a quantifiable measure which includes all responses such as setbacks as well as the types and amounts of armoring.

Terich, Thomas A.; Gabriel, Anthony D. 1987. Effect of erosion upon coastal property values. pp 2391-2401 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: The effect of long-term severe erosion upon coastal property values is tested at a site along the Pacific Coast of Washington State. Statistical analysis of mean sales values suggests the erosion has had little impact on land values. This conclusion must remain tenuous because of the nature of the site. The problems and issues of studying the economic impacts of coastal erosion are presented. (Author abstract)
>
> ANNOTATION: The potential of insurance may be a factor in erosion's effect on property values. The author found the assessor's lowering of property value for the purpose of tax assessment had a greater effect than erosion.

Ives, S.M.; Furuseth, O.J. 1988. Community response to coastal erosion: The view from two North Carolina beach areas. *Ocean and Shoreline Management* 11(3): 177-193.

> ANNOTATION: Research on response to coastal erosion suggest that residents of both communities are aware of the hazard, and view it as a natural process with which they must cope. They recognize that erosion risk is increased by human action, and hence are strongly in support of non-structural approaches at the local level. Residents also indicate strong support for post-disaster assistance from federal and state governments, moderate support for structural techniques, but relatively weak support for subsidized hazard insurance.

Kucma-Kenny, Gail A. and Karl F. Nordstrom. Communication of coastal erosion information to shorefront residents: the user perspective. p 327 in: *Coastal Zone '85: Proceedings of the symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ANNOTATION: According to managers and policy makers, coastal erosion problems are reaching critical proportions along much of the US Shorefront. These researchers

found that the public is not very interested in the problem unless they are being impacted.

Griggs, Gary B. 1987. California's retreating shoreline: The state of the problem. pp 1370-1383 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: Approximately 86 percent of California's 1715 km of shoreline is eroding. Nearly ten percent of this oceanfront has now been armored. With present day costs of shoreline protection varying from $1500 to $10,000/meter of oceanfront, the costs of protecting the 170 km of developed coastline still threatened by erosion amounts to $255 million to $1. 7 billion. Development of three types of coastal geomorphic environments, the beach itself, eroding cliffs or bluffs, and active sand dunes, has led to the problems and storm damage witnessed in recent years. Careful investigation of the recent geologic history of oceanfront sites prior to development is relatively straightforward and inexpensive, and is necessary to clearly evaluate the risks and expected erosion at any particular location. Once construction in a hazardous environment has taken place, the options available are severely reduced with expensive but somewhat temporary protective structures being the most common solution. (Author abstract) 7 refs.

Shipman, Hugh; Canning, Douglas, J. 1993. Cumulative environmental impacts of shoreline stabilization in Puget Sound. pp 2233-2242 in: *Coastal Zone '93 Coastal Zone: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: Although shore protection structures such as bulkheads and seawalls may provide protection to upland property owners, they bring with them numerous potential adverse environmental effects. As sections of Puget Sound's shoreline become increasingly armored, the cumulative impact of these environmental effects becomes a serious concern. The authors discuss a number of potential environmental problems that may result from shoreline armoring.

6.5 Marine Debris

Marine debris could be good indicator because it directly affects coastal scenic value and can also harm organisms through entanglement or ingestion. Articles in this field commonly describe the problem of marine debris and show how clean up events have an impact on public awareness and education (Kauffman and Brown, 1991). However, some have quantified the types and amounts of debris obtained. This is a good start, and comparisons can be used to evaluate some programs like the international ban on ocean dumping of plastics (O'Hara 1991). However, because different degrees of effort (e.g., the number of person-hours or the area of beach cleaned) can alter the amount of debris collected, simple volume measurements are not useful as an indicator environmental quality. Lindstedt (1989), by

adding the simple component of area, turns interesting information into a useful measurable indicator. The density of debris, e.g., items per 100 m^2 is a measurement that can be tracked to show improvement and to compare with measurements at other locations or areas.

One neglected aspect of marine debris is the amount of material submerged. Perhaps since it isn't such a visible project, it doesn't have a large constituency group. However, its potential impact on fish warrant its study as an indicator of environmental quality (Simmons 1993).

Kauffman, Jill; Brown, Maria. 1991. California Marine Debris action plan. pp 3390-3406 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: Trash in the oceans and on California's beaches are killing marine wildlife and fouling our beaches. To address this problem in California, the Center for Marine Conservation convened a statewide Marine Debris Steering Committee, in August 1989, comprised of representatives of federal, state, and local government, industry, science, education and conservation organizations. The Steering Committee evaluated the marine debris problem in California and developed 22 recommendations to reduce debris in the marine environment. The results were published in a report, the California Marine Debris Action Plan. During the 1989 California Coastal Cleanup, volunteers recorded the types and amounts of trash they collected from the beach. The information was analyzed by the Center for Marine Conservation and indicated that 54.75 percent of the debris collected was plastic with the biggest threat to California's marine environment from land-based sources. California also had the most entangled and dead wildlife of any Cleanup state in the nation. The cost to maintain clean beach areas are great. The cities of Santa Monica and Long Beach each spent more than $1 million in 1988-9 to clean their beaches and costs continue to rise. In recommendations put forth in the Action Plan, the Steering Committee identified the need to education the public about the harm of marine debris, proper disposal, and existing litter and dumping laws as a priority to effectively address the problem. Education must be conducted in conjunction with proper enforcement of the laws, continued research, and progressive waste management legislation. (Author abstract) 10 Refs.

O'Hara, Kathryn J. 1991. Cleaning north America's beaches. Volunteers across America monitor the quality of our coasts. pp 2157-2167 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: The Center for Marine Conservation (CMC) has established a National Marine Debris Database to involve citizens in the collection of standardized information on marine debris. A comparison of data from the 1988 and 1989 national beach cleanups showed that the composition of trash found on America's beaches has remained relatively unchanged despite the enactment of an international ban on ocean dumping of plastics. Plastics still account for most of the trash or approximately 63%. In 1989, approximately 60% of all debris was packaging and disposable plastic

products. Debris from ocean sources was found to be most prevalent in states bordering the Gulf of Mexico and North Pacific. More than 70 items reported were traceable to specific cruise line companies. Inadequate sewer systems, a land-based source of debris, are of particular concern in northeast coastal states and the Great Lakes. Volunteers also reported 65 cases of wildlife entanglement or ingestion of debris, most of which were birds entangled in plastic fishing line. (Author abstract)

Lindstedt, Dianne M.; Holmes, Joseph C. Jr. 1989. Debris is not a cheese: Litter in coastal Louisiana. pp 1297-1310 in: *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York

ABSTRACT: An 18-month study of six Louisiana beaches determined the extent, composition, and possible sources of beach litter. Data showed that from 2590 to 23,154 items may be encountered along any one-mile stretch of Louisiana beach, depending upon location and season, and that densities of litter ranged from 5 to 28 items per 100 m^2. Plastics constituted 47% of the total, followed by polystyrene at 16% and glass at 10%. Drink-related items accounted for 40% of the identifiable material; operational wastes, 21%; galley wastes, 15%; personal items, 11%; and fishing items, 6%. Litter laws already exist at state and federal levels. Strict enforcement of Annex V of MARPOL should significantly reduce plastic beach litter. Solutions to beach litter will come from public participation in adopt-a-beach programs and statewide clean-ups and from educational programs focusing on existing laws, proper disposal methods, recycling, and the threat litter poses to wildlife and public health. (Author abstract) 20 Refs.

Simmons, S.L.; Fricker, A.; Williams, A.T. 1993. Offshore/marine litter in Swansea bay, wales, UK. pp 2283-2296 in: *Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York

ABSTRACT: Offshore litter can originate from various sources; with land based (i.e., rivers and beaches), sewage disposal sites and sea dumping being the main source areas. Much work has been carried out on beach/riverine litter, but the problem of submerged marine litter has not been recognized and will worsen with time. White Oyster Ledge is an underwater reef located in 20 m of water some 4 km offshore in swansea Bay, UK. Litter entangled in 30 gill nets sited on this ledge was collected and quantified by number and weight(total number 3670, total weight 6367 g.). Sewage derived materials i.e., sanitary towels (by far the largest category), condoms, plastics and nappies accounted for 24% of the total number and 7% of total litter weight. The sanitary towels were subdivided into, panty liners 146, absorbent materials 21, mini-pads 188, press on towels 361 and unidentified 155. The Swansea conurbation greater than 200,000 people) theoretically is capable of flushing some 8000 towels daily into the sewage system . Of the general litter category, trawl netting, string/rope, paper, tyres etc accounted for less than 2% of the total numbers found, but 35% of the weight. Other major contributors were food wrappers together with clear/coloured plastics derived from beach and land sources. With respect to numbers and weights of total litter found, food wrappers and carrier bags comprised

8% and 9%; clear plastics 34% and 27%; coloured plastics 32% and 22% respectively. Litter in this sink area has an economical cost on commercial fishing as well as posing an ecological threat.

6.6 Public Participation

Public participation is an important secondary goal of the Coastal Zone Management Act. That is, it is identified as a desirable means of achieving the primary goals of the Act.

The CZMA reauthorization of 1990 required the states to assess the adequacy of their CZM Program, and to include public consultation and participation in the assessment and improvement strategy process. Unfortunately, no compilation or comparison of the public opinion survey processes and results has been completed.

Most of the literature that touches on public participation is descriptive. Swaminathan (1993) touches on the importance of using the public's perception when devising management plans. There is an abundance of papers addressing public participation in the form of citizen monitoring, e.g. Bromenshenk and Preston (1986), Wakeman and Derven (1987), Armitage et al. (1989), and Libster (1991). Christman and Frease (1993) show that when properly trained, volunteer generated data can be an efficient and effective adjunct to governmental monitoring programs. None of these papers addressed public opinion. No discussion was found which directly addresses public perceptions vs professional perceptions.

Swaminathan, M.S. 1993. Building an integrated ecological and livelihood security system for the coastal zone. pp. 23-34 in: *Sustainable Management of Coastal Ecosystems.* (Swaminathan, M.S.; Ramesh, R. eds). M.S. Swaminathan Res. Found.

> ABSTRACT: Anthropogenic pressures on the coastal ecosystems are increasing. Hence, there is a need for strengthening efforts in promoting the livelihood security of coastal communities on ecologically sustainable lines. Coastal management and monitoring systems need to be designed in such a manner that the people of the area participate actively in protecting the coastal ecosystem. Harmony within human kind, political action, public awareness and professional sensitivity are also equally important factors in sustainable management of coastal ecosystems. [abstract only]

Bromenshenk, J.J.; Preston, E. M. 1986. Public participation in environmental monitoring: A means of attaining network capability. *Environ. Monit. Assess.* 6(1): 35-47.

> ABSTRACT: In the Puget Sound region of the United States a task force of community volunteers using bees monitored environmental pollution. This paper discusses advantages and limitations of public involvement in the assessment of regional environmental problems, particularly with respect to biological monitoring. This approach not only yielded extensive information about pollution levels but also was very cost effective.

Wakeman, Thomas H.; Derven, Daphne L. 1987. Successful merging of scientific research and public participation. pp 394-398 in: *Coastal Zone '87, Proceedings of the Fifth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: This paper describes the on-going programs at the US Army Corps of Engineers' San Francisco Bay-Delta Model and Visitor Center that aim to broaden the general public's understanding and appreciation of science and scientific research. The Visitor Center offers the public, and more specifically school children, the opportunity to expand their knowledge of scientific research by providing access and descriptions of science in-action at an operating hydraulics laboratory. Ideas such as the experimental method, modeling and testing programs, are introduced in a simple and basic fashion to help provide familiarity with scientific vocabulary and methodologies. Furthermore the public is able to gain a greater appreciation and understanding of the geographical and hydraulic mechanisms affecting the region of San Francisco Bay including landforms, tidal influences and freshwater inflows into the estuary by viewing the Model.

Armitage, Thomas; Baptiste, Ellen; Ellet, Kathleen 1989. Citizen volunteer monitoring, a tool for estuarine management. pp 887-898 in: *Coastal Zone '89: Proceedings of the Sixth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: The Environmental Protection Agency is exploring the uses of citizen volunteer monitoring to support its mission of protecting and improving water quality in the nation's estuaries. This paper describes how successful volunteer estuarine monitoring programs can be developed, implemented, and maintained. Volunteer monitoring data can be collected and used to meet a number of different estuarine management objectives. Enforcement and compliance monitoring programs require quality assured and quality controlled data. Citizen monitoring can provide data to meet this objective, but it can also play a key role in building public support for action, and ultimately the political will to accomplish environmental goals. Citizen volunteer monitoring can augment monitoring programs already in existence at the federal, state, and local levels. Mobilization of citizen volunteers permits the collection of data that would not be available through conventional methods. (Author abstract) 4 Refs.

Liebster, Jack. 1991. California's Adopt-A-Beach. More than just a cleanup. pp 1242-1251 in: *Coastal Zone '91: Proceedings of the Seventh Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

> ABSTRACT: California's Adopt-A-Beach Cleanup and Recycling Program is in its seventh year of dramatic growth. Beginning as an annual one-day cleanup, it has now expanded year 'round and emphasizes broader coastal awareness. The Adopt-A-Beach program is structured to provide easy, accessible opportunities for participation, then to build upon those to bring participants to greater levels of understanding and concern about the broad range of coastal issues. The paper discusses how the program

has achieved its successful growth, and suggests opportunities for the future. (Author abstract) 5 Refs

Christman, Brian B.; Frease, Robert A. 1993. Assessing the quality of citizen volunteer monitoring. pp 2772-2786 in: *Coastal Zone '93: Proceedings of the eighth Symposium on Coastal and Ocean Management.* American Society of Civil Engineers, New York.

ABSTRACT: Total-error profiles and quality control charts are presented as quantitative techniques to determine acceptability of methodology and analyses for volunteer water quality monitoring programs. These techniques were used by the Volunteer Citizens' Water Quality Monitoring Network for the Indian River Lagoon, an estuarine monitoring program on Florida's central east coast. Network methods of analysis for dissolved oxygen, salinity and pH were acceptable across ranges of 2.4 to 11.3 mg/l, 4.0 to 35.7 g/kg and 7.2 to 8.4 pH units, respectively. The potential exists for an increase in the acceptable ranges. Twenty on-site assessments of volunteer analyses were subsequently conducted, and 95% of dissolved oxygen, 89% of salinity and 89% of pH results met quality control criteria. Unacceptable errors were resolved with retraining and supplemental instrumentation. The techniques can be tailored to individual program objectives and should prove useful in defining and assessing quality of volunteer generated data.

7. Summary and Conclusions

There is a large and diverse body of research dealing with environmental monitoring of coastal zone features and resources. However, few of the papers directly address environmental characterization, and even fewer do so in a way that conforms with our criteria for "useful indicators," i.e., providing an indicator that is outcome oriented, inexpensive, and easily understandable as an indicator of environmental quality. This chapter summarizes the results of the literature review and offers recommendations.

7.1 Direct Measurements and Bioindicators

There are many traditional indicators in this category. The direct measurement model can easily test for pH, dissolved oxygen levels, and concentration levels of a number of contaminants. However, routine or time series measurements can become costly. Moreover, the public seldom understands the meaning of most water quality data.

Bioindicators are likely more useful for the public because water quality information is then related to the health or fitness of a living organism. Bioindicators may also be less expensive than frequent direct measurements, and are likely a better measure of sediment and water quality in a dynamic environment. Quantitative measures exist or can easily be developed for bioindicators.

The move toward community-based or diversity index-based bioindicator research is too new to assess its value as an environmental quality indicator. Quantitative measures have not yet been developed.

7.2 Bivalves

Because of the large body of research and the degree of public understandability, bivalves would make a particularly good environmental indicator. Although they suffer from the same limitations of other individual species bioindicators in that they are not necessarily able to determine community level effects, they should nonetheless be one of the tools used to evaluate coastal zone quality. Coastal zone managers interested in water quality should consider using Mussel Watch information where appropriate, or if one is not near enough to give credible monitoring data, to try to set up a similar program.

7.3 Benthos

Research in this area has similar strengths and weaknesses to bioindicators. Individual bioindicators, e.g., tumors in flatfish or shellfish harvest closures tend to be readily understandable. However, there are few monitoring programs organized around these types of

indicators. The National Status and Trends Benthic Surveillance Project has the advantage of its large scale and long term of existence. Similar to the Mussel Watch program, it is another tool coastal zone mangers should consider in evaluating coastal zone quality.

Another attempt at improving this weakness focused on a number of community based models that will give a more environmental quality measurement. The abundance/biomass comparison and diversity indices could give a more useful measure of environmental quality, but again, the cost may include the loss of public acceptance.

7.4 Coastal Zone Management

Most of the papers found in this phase of the literature review do not have the same degree of quantifiable measurements found in the scientific literature.

Congress mentioned eight "improvement objectives" in their 1990 reauthorization of the CZMA. These objectives involved a (1) concern for wetlands, (2) coastal hazards, (3) public assess, (4) marine debris, (5) cumulative and secondary impacts, (6) special area management plans, (7) ocean resources, and (8) siting of energy and government facilities. Of these eight objectives, only coastal hazards, public access, and marine debris were addressed in the literature. Some articles on wetlands were discovered, but these mainly dealt with a description of restoration attempts or with arguments for wetland preservation.

7.4.1 Buffer Zones

Buffer zones might be one way to measure the effectiveness of programs designed to protect and preserve wetlands and other sensitive areas. Buffer zones can serve to maintain water quality, protect habitat values, and reduce erosion damage to structures. Still, this is an indirect assessment of the potential for wetlands preservation or water quality protection. Direct assessments would be more useful. Moreover, buffer zone widths recommended by the scientific community are often equal to or in excess of the management zone authorized under Washington's Shoreline Management Act. The SMA contemplates managing development within that zone, not setting it aside as a buffer.

7.4.2 Public Access

Public access has the potential to be a useful coastal zone quality indicator. To achieve this, public access inventory data should be developed and presented in a manner that includes a 'per capita' component. 'More public access' is a common concern, but how much is enough? More importantly, to determine appropriate levels of public access, managers need to know the patterns of use at existing sites at both the local and regional levels. In other words, managers need to be able to compare supply with demand. Measurements of individual site usage rates and the number of access sites per capita could allow this comparison. However, a note of caution should given. Increasing public access can have

undesirable environmental effects on other coastal zone amenities. Managers should weigh the two sides carefully.

7.4.3 Coastal Hazards

The literature on coastal hazards potentially relating to coastal quality indicators is scant. Some problems were described, e.g., the amount of armoring along the coast, which do suggest the potential for a measurable indicator, but more research needs to be done to develop appropriate indicators that would be useful as evaluative and monitoring tools.

7.4.4 Marine Debris

Marine debris density would be a useful indicator. Unfortunately, it is rarely used. This parameter highlights the difference between a more social goal like cleaning up a beach and educating the public, and a more scientific goal which could result in a cleaner beach and an educated public but which would also produce measurements that could be used to evaluate how clean a beach is compared to another. This type of data would take little extra effort at record keeping, but it would result in a much more useful measurement.

In the future, groups like the Center for Marine Conservation should request measurements of effort as well as the amount and types of debris collected. Other variables that could affect beach debris, such as a recent storm event or time between collections, also need to be recorded and taken into account. Nationally, a consistent recording format is also important.

7.4.5 Public Participation

Public perception itself is not an environmental quality indicator. However, public perception is an important part of determining the understandability of an indicator. Greater attention should be paid to research on public perceptions of coastal zone values and coastal zone quality.

7.5 Conclusions

One component frequently missing from the literature was a useful quantifiable measurement. Part of the reason for this involves the different degrees of established writings and theory. In general, the direct measurement and bioindicator models have been established much longer than the coastal zone management field and was thus more likely to have evolved to the point where they have developed and applied more quantifiable indicators.

The other factor responsible for this lack of quantification is the nature of the research. The direct measurement and bioindicator fields tended to approach the problem from a natural and physical science perspective. This approach is more conducive to quantifiable measurements. The coastal zone management field, on the other hand, seemed to approach the problem more from a land use perspective. This approach does not rely as heavily on

quantification or mathematical models. Therefore, there is not the tradition to describe results in rigorous, quantitative ways.

The other component frequently missing from most of the research, even when the research had a quantifiable measure, was utility, i.e., its value and usefulness to both coastal zone managers and the public. This feature applied equally to research in both the direct measurement and bioindicator fields and to the coastal zone management field. Simply put, scientific research is aimed at answering scientific questions and communicating the results to one's peers. Translation of scientific principals does not occur in the scientific literature. However, when authors specifically tried to develop "useful" environmental indicators they were generally successful

There are strong environmental indicators of water quality, which is an aspect of environmental quality, but is not the whole story. While there are many potential and promising indicators to help fill in what water quality cannot measure, they often lack in one or more of the three key components determining an indicator's utility, i.e., measurability, cost effectiveness, and a high degree of intuitiveness or understandability. Coastal managers need to devote more thought to identifying and developing indicators of coastal zone quality which capture the essence of the Coastal Zone Management Act and the Shoreline Management Act.